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A Simplified Procedure for the Routine Calculation of Coefficients of Utilisation Based on the Jones-Neidhart Data

By R. H. SIMONS, B.Sc., A.R.C.S. (*Member*)*

Summary

The preparation of tables of coefficients of utilisation from the Jones-Neidhart data is a much more lengthy process than from the Harrison-Anderson data. The method given in this paper is based on the Jones-Neidhart data, but the work involved in applying it is about the same as that for the Harrison-Anderson method. It also provides sufficient information for brightness calculations to be carried out.

Introduction

The Jones-Neidhart([1], [2]) method of determining coefficients of utilisation is the first that has been able to rival successfully that of Harrison-Anderson([3]) since its introduction nearly forty years ago. The main advantages claimed for this new method are that it is more accurate and that it provides a greater degree of flexibility by enabling brightness calculations to be carried out. However, in spite of these advantages, and the fact that in America it is the only I.E.S. approved method([4]), there is a reluctance to adopt it because of the increase in labour involved in its use. Although this increase is not as great as eightfold, as stated by Balogh([5]), it is sufficiently great for simplification and shortening of the calculations to be very necessary if the method is to gain general acceptance. Zaphyr and Horton([6]) have adapted the calculations so that they can be carried out on a digital computer, but unfortunately, not many manufacturers have one of these available. The purpose of this present paper is to describe an alternative method which is similar to that of Harrison-Anderson in its mode of calculating coefficients of utilisation, but is based on the Jones-Neidhart data. It also provides sufficient data for brightness calculations to be carried out if desired. In this method some of the accuracy of the Jones-Neidhart method is lost, but it will be shown that this loss is small.

Method

In the method described in this paper, the coefficients of utilisation of a fitting are found by breaking down its light distribution into components for which the utilisation factors have been precalculated by the Jones-Neidhart method. The sum of these utilisation factors in the correct proportions will then give the required coefficients of utilisation. Correct proportions in this connotation means the proportions in which it is necessary to combine the components to give the light distribution of the fitting.

The method of breaking down the light distribution of the fitting is similar to that of Harrison-Anderson, and is shown in Fig.1. The graphs are Rousseau diagrams, so the luminous flux is proportional to the area under the curves. It can be seen that the flux is divided into three components as follows: (1) Uniform Radial Component, (2) Lower Residual Component, (3) Upper Residual Component. These components are analogous to the horizontal, direct, and indirect components of Harrison-Anderson, but have been redesignated in the hope that the new names will make their function clearer.

Uniform Radial Component

In order to describe the lower and upper components by simple mathematical equations, it is convenient to make their intensity at 90° to the downward vertical (I_{90}) equal to zero. This is done by subtracting the uniform radial component from the distribution of the fitting. This component must therefore have its intensity at 90° equal to that of the fitting, but otherwise its form of candlepower distribution is quite arbitrary. Harrison-Anderson and Croft([7]) chose the sine distribution $I_\theta = I_{90} \sin \theta$, where I_θ = the intensity at any angle θ to the downward vertical.

This distribution which constituted their "horizontal component" has the drawback that the proportion of its flux reaching the working plane (or more precisely the direct ratio) is so small that

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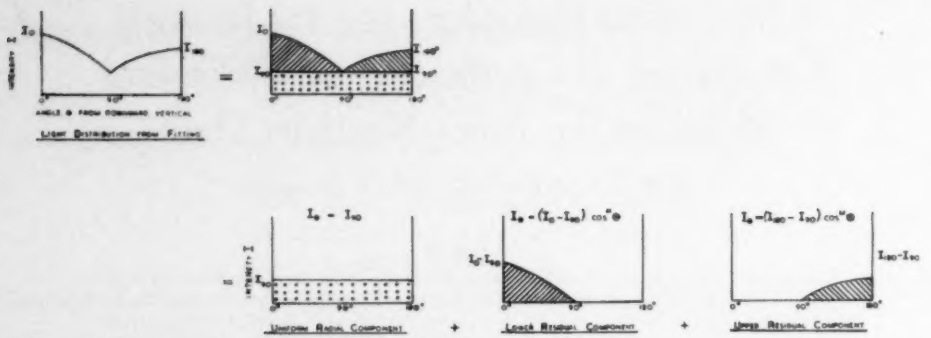

Fig.1. Rousseau diagrams showing analysis of the light distribution from a fitting into three components. The value of Cos θ from 90 to 180 deg. is taken to be positive and the values of N and M are chosen to give the correct percentage of flux in the 0 to 40 deg. and 140 to 180 deg. zones respectively.

it is impossible to use the Jones-Neidhart inter-reflection graphs, since they do not extend far enough into the low values.

It was therefore decided to use the alternative distribution (suggested by Croft) of a point source of light, for which $I_\theta = I_{0^\circ}$. Since this sends the light equally in all directions it is called the uniform radial component.

Besides having a sufficiently high direct ratio to enable the interreflection graphs to be used, this distribution has the added advantage that it accounts for more flux ($4\pi\ I_{0^\circ}$ as opposed to $\pi^2\ I_{0^\circ}$) than the sine distribution. In most cases this would tend to make the method more accurate, since the other two components can only be described approximately.

The flux in the radial component divided by that of the bare lamp is called the uniform radial fraction, that is :—

$$\text{Uniform Radial Fraction} = \frac{\text{Flux in Uniform Radial Component}}{\text{Bare Lamp Flux}}$$

The utilisation factors for the uniform radial component were found by the Jones-Neidhart method for a spacing/mounting height ratio of 1.0, and are given in the work sheets in Appendix D. They are the lower figures in each cell, e.g. for suspended fittings Room Index A, they are 0.209, 0.151, 0.109, etc., omitting the right-hand column.

Lower Residual Component

The remaining downward flux after subtraction of the uniform radial component is called the lower residual component, and can usually be described by means of the equation, due to Croft,

$$I_\theta = I_0 \cos^n \theta.$$

The values of n can be chosen to give any desired percentage of flux in the 0°-40° zone from about 30 per cent to nearly 100 per cent, and values of n have been calculated by Croft to cover this range in 5 per cent steps. This percentage is known as the flux ratio and gives an arbitrary measure of the degree of concentration of the light.

The utilisation factors for the resulting curves were found by using the Jones-Neidhart method and are tabulated in Appendices A and B for suspended and ceiling mounted fittings respectively.

Thus when dealing with an actual fitting, the flux ratio for the lower residual component has to be calculated in order to find which table of utilisation factors is applicable. This is most conveniently done by use of the following formula :

$$\text{Flux ratio} = \frac{\%\ \text{Flux from fitting in 0°-40° zone} - 11.7 \times \text{URF}}{\text{Lower Residual Fraction}}$$

where, $\text{Lower Residual Fraction} = \dfrac{\text{Flux in Lower residual component}}{\text{Bare Lamp Flux}}$

and, $\%$ Flux from fitting in 0°-40° zone $= \dfrac{\text{Flux from fitting in 0°-40° zone}}{\text{Bare Lamp Flux}}$

The last term in the numerator of the flux ratio is the percentage of the uniform radial component which lies in the 0°-40° zone, that is $0.5\,(1 - \cos 40^\circ) \times 100$.

Upper Residual Component

The remaining upward flux after subtracting the uniform radial component constitutes the upper residual component and could be treated in a similar manner to the lower residual component. However, it was found that for suspended fittings, the utilisation factors for an upper residual component with a flux ratio of 30 per cent differ little from those for an upper residual component with a flux ratio of nearly 100 per cent, so that the average value for these two extreme distributions was taken as providing the least amount of error.

Jones and Neidhart give the utilisation factors of the upper residual components for ceiling mounted fittings, and these values were used without any further approximation. In Appendix D they are the top figures in each cell, e.g. for suspended fittings Room Index A, they are 0.15, 0.10, 0.05, 0.11, etc., omitting the right-hand column.

Procedure for Finding Coefficients of Utilisation for Suspended Fittings Demonstrated with Example

Data

Per cent flux in 0°-40° zone :	18.6
Light output ratio :	80.3 per cent
Light output ratio up :	36.9 per cent
Light output ratio down :	43.4 per cent
Total bare lamp flux :	1,240 lumens
Intensity at 90° :	51.5 candelas

Working out

The method can most conveniently be carried out on the Work Sheet 1 given in Appendix D, but for clarity the various steps are given in the body of the text below.

(1) Uniform Radial Fraction =

$$\frac{4\pi \times \text{Intensity at } 90^\circ}{\text{Bare Lamp Output}}$$

$$= \frac{12.57 \times 51.5}{1{,}240}$$

$$= 0.522$$

(2) Lower Residual Fraction =

$$\frac{\text{L.O.R. Down}}{100} - \tfrac{1}{2}\text{Uniform Radial Fraction}$$

$$= .434 - (\tfrac{1}{2} \times 0.522)$$

$$= .173$$

(3) Upper Residual Fraction =

$$\frac{\text{L.O.R. Up}}{100} - \tfrac{1}{2}\text{ Uniform Radial Fraction}$$

$$= .369 - (\tfrac{1}{2} \times 0.522)$$

$$= .108$$

(4) Check on Working

$$\text{Uniform Radial} + \text{Lower Residual} + \text{URF} = \frac{\text{L.O.R.}}{100}$$

$.522 + .173 + .108 = .803$ which is correct.

(5) Flux Ratio of Lower Residual Component

The lower residual component is classified according to the percentage of its flux in the 0°-40° zone, that is, its flux ratio.

$$\text{Flux ratio} = \frac{\%\text{ Flux in } 0^\circ\text{-}40^\circ \text{ zone} - (11.7 \times \text{URF})}{\text{Lower Residual Fraction}}$$

$$= \frac{18.6 - (11.7 \times 0.522)}{.173}$$

$$= 72\% \text{ of the Lower Residual Fraction}$$

URF—Uniform Radial Fraction.

The utilisation factors for this flux ratio, which are given in Table 9 in Appendix A, are then written under the appropriate utilisation factors for the radial component on the Work Sheet 1 for suspended fittings.

(6) Coefficients of utilisation

The coefficients of utilisation are given by the sum of the products of the utilisation factors with their respective components.

Thus for a room of index A, ceiling reflection 75 per cent, wall reflection 50 per cent, the working is as shown in Table 1 below.

Table 1

Calculation of coefficient of utilisation from the sum of the products of the utilisation factors with their respective fractions

Component	Utilisation Factor	Fraction	Product
Upper Residual	.15	.108	.016
Uniform Radial	.209	.522	.109
Lower Residual	.612	.173	.106
		Total ...	.231

Therefore coefficient of utilisation to two significant figures is 0.23.

Each square on the work sheets is worked out in a similar fashion to Table 1.

Negative Upper Residual Fractions

If half the radial fraction is greater than the fraction of upward flux from the fitting, the upper residual fraction will be negative. In this case the procedure is the same as before, except

hat the product of the upper residual fraction with the utilisation factor is subtracted from the other two products; that is, the coefficient of utilisation is the algebraic sum of the three products.

Ceiling mounted fittings

The procedure for finding the coefficient of utilisation for ceiling mounted fittings is the same as for suspended fittings, except that the tables in Appendix B, which are applicable to ceiling mounted fittings, are used.

Brightness Data

The brightness of the walls and ceiling is most conveniently found by determining what Jones and Neidhart call the "wall coefficients of utilisation" and "ceiling coefficients of utilisation." These could be found in a similar manner to those for the working plane, but it is felt that this would involve the production of tables of coefficients of utilisation which would seldom be used. It was, therefore, decided that it would be sufficient to supply coefficients of utilisation for the ceiling with zero wall and floor reflectance. This gives the fraction of lamp flux reaching the ceiling directly, and enables Jones-Neidhart interreflection graphs[2] to be used.

The coefficients of utilisation for the ceiling are found using the same three components as previously, except that for suspended fittings the distribution of the upper residual component has to be classified.

Upper residual components with a flux ratio less than 23 per cent often occur, and unfortunately the value of n in Croft's equation $I_\theta = I_0 \cos^n \theta$ is negative in these cases. This makes the value of I_{90} infinite which can never occur in practice. To overcome this, the difference between two curves with different values of n was taken to give the required flux ratios. The exact procedure which was adopted is given in Appendix F.

The ceiling utilisation factors for the uniform radial and lower residual component are given on the second and third lines respectively in each cell of the right-hand column of the work sheets in Appendix D. The ceiling utilisation factors for upper residual components are given on the top line of each cell for ceiling mounted fittings, and in Appendix C for suspended fittings.

Procedure for Finding Ceiling Coefficients of Utilisation for Suspended Fittings (Floor and Wall Reflectance Zero)

Extra data required (*for suspended fittings only*)

Per cent flux in 140°-180° zone : 11.65

Working out

(1) Flux ratio of Upper Residual Component

$$\text{Flux ratio} = \frac{\%\ \text{Flux in } 140°\text{-}180°\ \text{zone} - 11.7 \times \text{URF}}{\text{Upper Residual Fraction}}$$

$$= \frac{11.65 - (11.7 \times 0.522)}{.108}$$

$$= 67 \text{ per cent of Upper Residual Fraction}$$

The utilisation factors for an upper residual component having this flux percentage can be found in Appendix C. They are then written in the appropriate spaces above the ceiling utilisation factors for the uniform radial component on the right-hand column of the work sheet, and the ceiling coefficients of utilisation are found in the same way as those for the working plane.

Additional Information Available from Tables of Coefficients of Utilisation

(1) *The Jones-Neidhart direct and ceiling ratio*

From the table of coefficients of utilisation for the fitting :—

C of U (wall and ceiling reflectance nil) = 0.134

Ceiling C of U (wall and floor reflectance nil) = 0.160

Direct ratio = C of U (wall and ceiling reflectance nil)/Light output ratio down

Therefore direct ratio for Room Index A = .134/.434

= .31

Similarly ceiling ratio for Room Index A = C of U ceiling (wall and floor reflectance nil)/Light output ratio up

= .160/.369

= .43

From these ratios, the brightness of the walls and ceiling can be found using the Jones-Neidhart interreflection graphs[2].

(2) *Iso-lux diagrams*

If an iso-lux diagram for the fitting is available, its value can be enhanced by adding the illumination due to interreflected light to that already given on the diagram. This can easily be found by subtracting the coefficient of utilisation for nil ceiling and wall reflectance from the coefficient for the ceiling and wall reflectance under consideration.

For example with the fitting already considered, supposing it is required to find the illumination due to interreflected light in a Room Index A, with ceiling reflectance 75 per cent and wall reflectance 50 per cent.

C of U for 75 per cent ceiling reflectance and 50 per cent wall reflectance = 0.23
(As found in Table 1)

C of U for 0 per cent ceiling and wall reflectance = 0.13

Difference = 0.10

therefore the flux interreflected
= Difference of C's of U × Bare Lamp Output
= 0.10 × 1,240
= 124 lumens per fitting

If the area of the floor is A sq. ft., then mean illumination due to interreflection

$$= \frac{\text{Flux inter-reflected}}{A}$$

$$= \frac{124}{A} \text{ lumens per sq. ft. per fitting}$$

This procedure assumes that the interreflected flux is uniformly distributed, which is only approximately true.

Tables of Coefficients of Utilisation

A suggested form of layout of tables of coefficients of utilisation is shown in Appendix E and is designed to show the results in a comprehensive form. Column L gives the coefficients of utilisation for rooms with zero wall and ceiling reflectance, and column M gives the coefficients of utilisation for the ceiling with zero wall and floor reflectance.

Accuracy of the Results Compared with the Jones-Neidhart Method

This method has been compared with that of Jones-Neidhart on eight fittings with widely different distributions, and it was considered that the agreement with the Jones-Neidhart method was good. Sixteen coefficients were worked out for each fitting, eight for Room Index A, and eight for Room Index J. Table 2, which is based on a total of 128 readings, shows the distribution of errors.

The error was obtained by subtracting the coefficients of utilisation as calculated by the method described in this paper from that calculated by the Jones-Neidhart method.

Comparison of the work involved in applying the Jones-Neidhart Method, and the Proposed Method

The principal reason why the Jones-Neidhart method is so lengthy is that the inter-reflected flux has to be read from graphs. For each coefficient of utilisation this has to be done twice for suspended fittings or once for ceiling mounted fittings, which in the preparation of the usual table of 80 coefficients makes the work very tedious and lengthy. In the I.E.S. proposed modification(8) tables are substituted for graphs which tends to make the work even more laborious since it is necessary to interpolate nearly every time a utilisation factor is looked up. In these tables, however, a simplification has been effected by adding the direct ratio onto the downward reflected component, thus saving a step.

The advantage of the method presented in this paper is that once the values of the three components have been calculated, and the appropriate utilisation factors for the lower residual component written down, the remainder of the work can be undertaken by personnel who have no knowledge of photometry. This has been substantiated by actual experience, and it enables tables of coefficients to be produced for each new type of fitting without increasing the work to be carried out by the photometric laboratory.

Table 2

Distribution of errors when the proposed method is compared with that of Jones-Neidhart

	Error						
	−.03	−.02	−.01	.00	+.01	+.02	+.03
Frequency as percentage of total	0.0	0.8	25.0	53.1	19.5	1.6	0.0

Limitations of the Method

The utilisation factors given in the tables in this paper are calculated for fittings at a spacing-to-mounting height ration of 1.0. It would be necessary to calculate new tables if coefficients of utilisation were required at other spacings.

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Appendix A

Utilisation Factors of Lower Residual Components for Suspended Fittings

Table 1

Utilisation Factors for Lower Residual Components Suspended Fittings

10 per cent Floor Reflection Factor
Flux Ratio : 30%-35%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.340	.280	.240	.333	.277	.240	.277	.240	.226
B	.432	.366	.322	.420	.364	.318	.362	.318	.304
C	.507	.435	.387	.490	.430	.381	.423	.380	.365
D	.583	.509	.457	.563	.500	.450	.492	.450	.431
E	.643	.568	.513	.623	.559	.507	.550	.507	.487
F	.724	.655	.593	.700	.640	.590	.630	.587	.557
G	.779	.713	.660	.753	.695	.652	.685	.649	.625
H	.821	.759	.709	.793	.740	.700	.727	.692	.661
I	.876	.825	.780	.849	.806	.768	.792	.760	.734
J	.910	.860	.820	.879	.840	.808	.823	.796	.770

Table 2

Utilisation Factors for Lower Residual Components Suspended Fittings

10 per cent Floor Reflection Factor
Flux Ratio : 35%-40%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.373	.314	.279	.365	.312	.277	.312	.277	.263
B	.470	.408	.365	.458	.405	.360	.403	.360	.348
C	.548	.482	.435	.533	.475	.428	.468	.428	.413
D	.623	.552	.505	.605	.547	.497	.540	.500	.481
E	.683	.615	.563	.665	.608	.560	.598	.557	.537
F	.760	.697	.645	.738	.684	.637	.672	.630	.615
G	.815	.755	.710	.793	.740	.700	.727	.698	.674
H	.855	.799	.754	.827	.780	.745	.763	.736	.714
I	.905	.860	.820	.880	.842	.807	.828	.799	.776
J	.935	.893	.860	.908	.875	.845	.858	.833	.810

Table 3

Utilisation Factors for Lower Residual Components
Suspended Fittings

10 per cent Floor Reflection Factor
Flux Ratio : 40%-45%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.405	.345	.310	.395	.345	.307	.345	.307	.295
B	.505	.445	.403	.492	.440	.397	.440	.397	.386
C	.583	.520	.475	.567	.517	.472	.509	.470	.454
D	.657	.592	.545	.640	.583	.537	.577	.539	.522
E	.715	.652	.604	.697	.643	.600	.636	.600	.579
F	.793	.735	.686	.771	.720	.680	.710	.674	.657
G	.845	.786	.745	.820	.771	.735	.762	.732	.711
H	.880	.830	.789	.855	.812	.778	.800	.773	.750
I	.927	.885	.850	.901	.868	.837	.855	.830	.806
J	.953	.917	.885	.926	.895	.870	.880	.860	.836

Table 4

Utilisation Factors for Lower Residual Components
Suspended Fittings

10 per cent Floor Reflection Factor
Flux Ratio : 45%-50%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.440	.387	.353	.435	.387	.352	.386	.352	.339
B	.545	.487	.448	.533	.483	.443	.482	.443	.432
C	.621	.562	.518	.605	.557	.513	.552	.513	.500
D	.695	.635	.593	.665	.628	.585	.622	.585	.569
E	.752	.697	.652	.737	.687	.648	.680	.645	.628
F	.822	.770	.728	.803	.755	.720	.747	.714	.697
G	.857	.810	.778	.847	.802	.770	.795	.767	.746
H	.902	.857	.820	.880	.840	.810	.828	.803	.782
I	.943	.908	.875	.920	.890	.862	.875	.855	.832
J	.970	.935	.910	.944	.919	.897	.902	.885	.861

Table 5

Utilisation Factors for Lower Residual Components
Suspended Fittings

10 per cent Floor Reflection Factor
Flux Ratio : 50%-55%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.474	.423	.390	.467	.422	.387	.422	.387	.377
B	.580	.527	.487	.567	.523	.483	.520	.483	.473
C	.654	.600	.560	.640	.594	.553	.590	.553	.540
D	.725	.670	.630	.710	.661	.622	.655	.623	.607
E	.778	.724	.683	.762	.717	.679	.709	.677	.660
F	.849	.799	.760	.830	.785	.754	.769	.749	.732
G	.890	.844	.809	.870	.828	.800	.815	.799	.778
H	.920	.879	.845	.900	.864	.834	.845	.829	.809
I	.960	.927	.898	.935	.910	.885	.894	.880	.855
J	.982	.952	.929	.957	.935	.915	.917	.904	.880

Table 6

Utilisation Factors for Lower Residual Components
Suspended Fittings

10 per cent Floor Reflection Factor
Flux Ratio : 55%-60%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.506	.456	.424	.500	.456	.423	.457	.423	.413
B	.611	.560	.525	.600	.556	.520	.555	.520	.510
C	.686	.631	.596	.672	.628	.590	.624	.590	.578
D	.752	.701	.664	.739	.694	.657	.687	.656	.643
E	.802	.754	.715	.789	.746	.710	.738	.710	.693
F	.868	.820	.784	.850	.807	.778	.800	.773	.759
G	.909	.865	.833	.889	.851	.825	.847	.824	.802
H	.934	.898	.865	.914	.882	.854	.870	.850	.830
I	.972	.941	.915	.949	.924	.901	.912	.896	.873
J	.990	.964	.940	.966	.945	.928	.929	.916	.893

Table 7

Utilisation Factors for Lower Residual Components
Suspended Fittings

10 per cent Floor Reflection Factor
Flux Ratio: 60%-65%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.544	.495	.465	.535	.495	.465	.496	.465	.454
B	.646	.600	.564	.634	.594	.560	.592	.560	.550
C	.717	.667	.635	.706	.664	.629	.660	.630	.617
D	.779	.732	.699	.768	.725	.691	.719	.691	.678
E	.826	.781	.747	.815	.775	.741	.765	.742	.725
F	.889	.846	.815	.871	.833	.807	.827	.802	.788
G	.925	.886	.856	.906	.873	.847	.869	.845	.826
H	.950	.914	.887	.930	.902	.875	.890	.870	.851
I	.981	.954	.930	.960	.937	.916	.921	.911	.889
J	1.000	.975	.955	.976	.957	.941	.940	.930	.907

Table 8

Utilisation Factors for Lower Residual Components
Suspended Fittings

10 per cent Floor Reflection Factor
Flux Ratio: 65%-70%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.579	.536	.506	.571	.535	.504	.535	.504	.496
B	.680	.636	.604	.670	.631	.598	.630	.598	.590
C	.747	.703	.672	.738	.698	.666	.694	.667	.655
D	.805	.763	.731	.795	.755	.725	.750	.725	.712
E	.850	.808	.776	.837	.801	.770	.796	.771	.756
F	.907	.868	.838	.890	.856	.830	.849	.828	.813
G	.938	.902	.875	.918	.889	.867	.885	.866	.846
H	.960	.929	.902	.940	.917	.890	.904	.885	.868
I	.991	.966	.944	.970	.950	.930	.938	.925	.903
J	1.006	.984	.965	.984	.967	.951	.948	.940	.918

Table 9

Utilisation Factors for Lower Residual Components
Suspended Fittings

10 per cent Floor Reflection Factor
Flux Ratio: 70%-75%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.612	.570	.543	.604	.569	.540	.569	.540	.533
B	.710	.669	.639	.700	.667	.633	.662	.633	.627
C	.777	.732	.705	.766	.729	.700	.722	.700	.689
D	.829	.790	.760	.819	.781	.755	.776	.753	.742
E	.870	.830	.802	.858	.823	.795	.817	.798	.782
F	.921	.885	.859	.905	.874	.850	.867	.847	.834
G	.951	.917	.894	.934	.905	.885	.900	.882	.865
H	.973	.942	.918	.952	.930	.908	.919	.900	.885
I	.998	.974	.954	.977	.959	.940	.945	.937	.914
J	1.013	.991	.973	.990	.973	.961	.957	.950	.928

Table 10

Utilisation Factors for Lower Residual Components
Suspended Fittings

10 per cent Floor Reflection Factor
Flux Ratio: 75%-80%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.655	.619	.593	.649	.617	.590	.616	.590	.583
B	.745	.706	.680	.735	.703	.675	.700	.675	.668
C	.804	.766	.741	.795	.762	.735	.756	.736	.725
D	.853	.817	.790	.844	.811	.787	.807	.786	.774
E	.890	.855	.829	.879	.848	.823	.842	.825	.810
F	.937	.904	.880	.922	.894	.871	.885	.869	.855
G	.964	.933	.912	.945	.922	.903	.917	.900	.883
H	.981	.952	.931	.961	.940	.920	.929	.914	.898
I	1.004	.985	.965	.984	.968	.950	.955	.947	.924
J	1.019	1.000	.985	.997	.982	.970	.967	.960	.938

Table 11

Utilisation Factors for Lower Residual Components
Suspended Fittings

10 per cent Floor Reflection Factor
Flux Ratio : 80%-85%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.698	.664	.643	.693	.663	.637	.663	.637	.632
B	.781	.746	.723	.772	.744	.720	.741	.720	.711
C	.833	.800	.776	.826	.795	.772	.790	.772	.762
D	.878	.845	.820	.868	.839	.816	.834	.815	.805
E	.910	.878	.856	.896	.871	.850	.866	.850	.837
F	.951	.921	.900	.937	.912	.891	.906	.888	.876
G	.976	.948	.928	.958	.938	.920	.930	.915	.900
H	.993	.966	.946	.974	.955	.936	.945	.930	.914
I	1.012	.994	.976	.991	.977	.961	.965	.957	.936
J	1.026	1.006	.993	1.003	.990	.979	.974	.969	.946

Table 12

Utilisation Factors for Lower Residual Components
Suspended Fittings

10 per cent Floor Reflection Factor
Flux Ratio : 85%-90%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.747	.718	.700	.744	.718	.695	.715	.695	.690
B	.821	.791	.771	.813	.787	.770	.787	.770	.761
C	.867	.836	.816	.860	.834	.814	.829	.816	.804
D	.904	.847	.853	.895	.870	.850	.865	.850	.840
E	.931	.903	.883	.921	.896	.878	.892	.878	.866
F	.966	.942	.921	.952	.931	.912	.923	.910	.899
G	.988	.963	.948	.970	.952	.938	.947	.934	.919
H	1.001	.978	.961	.982	.969	.950	.957	.943	.929
I	1.020	1.003	.988	1.000	.987	.971	.976	.970	.948
J	1.031	1.016	1.003	1.010	.997	.989	.982	.977	.956

Table 13

Utilisation Factors for Lower Residual Components
Suspended Fittings

10 per cent Floor Reflection Factor
Flux Ratio : 90%-95%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.802	.776	.764	.800	.776	.758	.775	.758	.755
B	.863	.837	.821	.856	.833	.817	.834	.817	.812
C	.900	.876	.859	.894	.871	.855	.866	.855	.847
D	.931	.905	.890	.924	.902	.885	.898	.885	.877
E	.954	.930	.916	.945	.925	.910	.923	.910	.898
F	.983	.960	.945	.970	.950	.935	.943	.933	.922
G	1.000	.980	.966	.984	.970	.957	.965	.952	.938
H	1.013	.992	.978	.996	.985	.967	.972	.960	.946
I	1.027	1.014	1.000	1.010	.999	.985	.985	.983	.961
J	1.038	1.024	1.012	1.017	1.005	.998	.990	.988	.967

Table 14

Utilisation Factors for Lower Residual Components
Suspended Fittings

10 per cent Floor Reflection Factor
Flux Ratio : 95%-100%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.885	.868	.856	.882	.866	.854	.864	.854	.851
B	.926	.904	.895	.918	.903	.892	.901	.892	.887
C	.948	.929	.917	.943	.925	.915	.921	.916	.908
D	.970	.950	.940	.964	.946	.936	.944	.935	.928
E	.985	.969	.956	.979	.962	.952	.961	.952	.941
F	1.004	.986	.975	.993	.980	.967	.972	.965	.954
G	1.017	1.000	.990	1.002	.992	.980	.986	.977	.963
H	1.026	1.010	.999	1.009	1.002	.987	.990	.981	.967
I	1.038	1.027	1.016	1.020	1.013	1.001	.998	.998	.977
J	1.047	1.035	1.026	1.026	1.018	1.012	1.001	1.001	.980

Table 1

Utilisation Factors for Lower Residual Components
Ceiling Mounted Fittings

10 per cent Floor Reflection Factor
Flux Ratio : 30%-35%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.369	.297	.246	.356	.293	.243	.289	.243	.226
B	.465	.386	.327	.450	.380	.326	.373	.323	.304
C	.537	.455	.394	.518	.443	.389	.436	.387	.365
D	.610	.526	.462	.585	.513	.458	.503	.453	.431
E	.669	.585	.521	.639	.571	.515	.560	.511	.487
F	.735	.660	.596	.703	.642	.588	.627	.580	.557
G	.799	.729	.670	.766	.708	.660	.693	.651	.625
H	.830	.766	.710	.796	.741	.697	.726	.687	.661
I	.891	.834	.786	.856	.811	.773	.794	.762	.734
J	.920	.870	.828	.884	.846	.810	.828	.798	.770

Table 2

Utilisation Factors for Lower Residual Components
Ceiling Mounted Fittings

10 per cent Floor Reflection Factor
Flux Ratio : 35%-40%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.401	.331	.282	.389	.327	.280	.324	.280	.263
B	.503	.427	.371	.488	.420	.369	.414	.366	.348
C	.577	.499	.441	.558	.487	.438	.481	.434	.413
D	.650	.571	.511	.625	.558	.507	.549	.503	.481
E	.709	.630	.571	.680	.617	.565	.606	.559	.537
F	.778	.711	.653	.747	.693	.645	.678	.637	.615
G	.833	.771	.718	.803	.751	.708	.736	.698	.674
H	.868	.811	.762	.836	.788	.749	.772	.739	.714
I	.918	.870	.828	.886	.846	.814	.830	.802	.776
J	.946	.903	.867	.912	.880	.850	.862	.837	.810

Table 3

Utilisation Factors for Lower Residual Components
Ceiling Mounted Fittings

10 per cent Floor Reflection Factor
Flux Ratio : 40%-45%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.430	.362	.314	.417	.358	.311	.354	.311	.295
B	.536	.463	.408	.521	.456	.405	.450	.405	.386
C	.610	.536	.482	.591	.524	.478	.519	.474	.454
D	.682	.607	.551	.658	.595	.546	.586	.543	.522
E	.740	.667	.611	.713	.654	.605	.643	.600	.579
F	.807	.746	.694	.779	.730	.686	.715	.677	.657
G	.859	.803	.753	.831	.782	.743	.769	.735	.711
H	.892	.841	.797	.862	.819	.784	.803	.774	.750
I	.937	.894	.857	.907	.872	.844	.855	.831	.806
J	.970	.924	.893	.931	.902	.875	.884	.861	.836

Table 4

Utilisation Factors for Lower Residual Components
Ceiling Mounted Fittings

10 per cent Floor Reflection Factor
Flux Ratio : 45%-50%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.468	.402	.357	.456	.397	.355	.395	.355	.339
B	.573	.505	.453	.558	.498	.452	.492	.449	.432
C	.648	.578	.527	.630	.567	.523	.560	.520	.500
D	.719	.648	.597	.696	.637	.593	.629	.589	.569
E	.778	.711	.659	.750	.697	.653	.687	.648	.628
F	.839	.781	.733	.810	.765	.725	.750	.717	.697
G	.883	.832	.787	.856	.813	.778	.799	.768	.746
H	.915	.868	.828	.885	.845	.814	.831	.804	.782
I	.956	.915	.882	.925	.894	.868	.878	.856	.832
J	.980	.945	.916	.947	.922	.899	.905	.886	.861

Table 5

Utilisation Factors for Lower Residual Components
Ceiling Mounted Fittings

10 per cent Floor Reflection Factor
Flux Ratio : 50%-55%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.500	.438	.395	.489	.433	.392	.432	.392	.377
B	.607	.542	.494	.593	.536	.491	.530	.489	.473
C	.680	.614	.566	.662	.604	.562	.598	.559	.540
D	.748	.682	.634	.727	.671	.630	.663	.626	.607
E	.800	.738	.690	.775	.726	.684	.715	.679	.660
F	.863	.811	.767	.836	.795	.759	.781	.751	.732
G	.906	.859	.818	.879	.840	.809	.827	.799	.778
H	.933	.890	.854	.906	.869	.841	.855	.831	.809
I	.971	.935	.905	.941	.914	.891	.898	.879	.855
J	.992	.960	.935	.960	.939	.918	.922	.905	.880

Table 6

Utilisation Factors for Lower Residual Components
Ceiling Mounted Fittings

10 per cent Floor Reflection Factor
Flux Ratio : 55%-60%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.531	.471	.430	.521	.467	.428	.464	.428	.413
B	.638	.576	.530	.624	.570	.528	.564	.526	.510
C	.709	.648	.603	.693	.638	.599	.632	.596	.578
D	.775	.713	.669	.755	.703	.665	.695	.661	.643
E	.824	.767	.722	.800	.755	.716	.745	.711	.693
F	.883	.834	.793	.857	.819	.785	.805	.777	.759
G	.921	.879	.841	.896	.860	.832	.848	.822	.802
H	.947	.908	.875	.920	.887	.861	.873	.851	.830
I	.982	.949	.922	.953	.928	.908	.913	.896	.873
J	1.000	.971	.948	.969	.950	.931	.933	.917	.893

Table 7

Utilisation Factors for Lower Residual Components
Ceiling Mounted Fittings

10 per cent Floor Reflection Factor
Flux Ratio : 60%-65%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.566	.509	.470	.556	.506	.468	.503	.468	.454
B	.670	.612	.569	.657	.606	.567	.601	.565	.550
C	.741	.683	.641	.724	.673	.637	.667	.633	.617
D	.802	.745	.703	.782	.735	.699	.726	.695	.678
E	.848	.795	.754	.825	.783	.747	.773	.742	.725
F	.904	.859	.821	.879	.844	.814	.830	.805	.788
G	.938	.899	.865	.913	.881	.856	.868	.846	.826
H	.959	.925	.895	.934	.904	.882	.891	.871	.851
I	.993	.963	.938	.965	.942	.924	.927	.911	.889
J	1.009	.982	.962	.979	.961	.944	.945	.930	.907

Table 8

Utilisation Factors for Lower Residual Components
Ceiling Mounted Fittings

10 per cent Floor Reflection Factor
Flux Ratio : 65%-70%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.602	.548	.511	.593	.544	.510	.542	.510	.496
B	.702	.648	.608	.690	.642	.604	.637	.602	.590
C	.769	.716	.678	.754	.707	.674	.702	.671	.655
D	.826	.773	.736	.808	.764	.732	.756	.728	.712
E	.870	.821	.784	.848	.810	.777	.800	.772	.756
F	.920	.879	.846	.897	.865	.838	.852	.829	.813
G	.951	.916	.884	.927	.898	.875	.886	.865	.846
H	.972	.940	.912	.947	.919	.898	.906	.888	.868
I	1.001	.974	.952	.974	.954	.937	.939	.925	.903
J	1.016	.993	.972	.987	.970	.955	.954	.941	.918

Table 9

Utilisation Factors for Lower Residual Components
Ceiling Mounted Fittings

10 per cent Floor Reflection Factor
Flux Ratio: 70%-75%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.633	.582	.548	.624	.579	.546	.576	.546	.533
B	.733	.682	.644	.720	.676	.642	.671	.640	.627
C	.796	.746	.711	.781	.738	.707	.733	.703	.689
D	.848	.800	.765	.831	.790	.760	.783	.757	.742
E	.888	.843	.808	.866	.832	.802	.823	.797	.782
F	.935	.897	.866	.912	.883	.858	.870	.850	.834
G	.963	.932	.903	.940	.914	.893	.902	.883	.865
H	.982	.953	.928	.958	.933	.915	.920	.904	.885
I	1.008	.983	.963	.981	.963	.948	.948	.936	.914
J	1.022	1.000	.982	.994	.979	.964	.962	.951	.928

Table 10

Utilisation Factors for Lower Residual Components
Ceiling Mounted Fittings

10 per cent Floor Reflection Factor
Flux Ratio: 75%-80%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.675	.628	.597	.667	.625	.595	.623	.595	.583
B	.765	.718	.684	.753	.713	.682	.708	.680	.668
C	.823	.778	.746	.810	.770	.742	.765	.739	.725
D	.871	.827	.796	.855	.818	.792	.812	.788	.774
E	.908	.867	.836	.888	.856	.830	.847	.824	.810
F	.948	.914	.884	.927	.901	.879	.888	.870	.855
G	.974	.946	.920	.952	.929	.911	.917	.901	.883
H	.991	.964	.941	.968	.944	.927	.932	.917	.898
I	1.014	.991	.972	.988	.971	.958	.956	.945	.924
J	1.028	1.008	.992	1.000	.987	.974	.969	.960	.938

Table 11

Utilisation Factors for Lower Residual Components
Ceiling Mounted Fittings

10 per cent Floor Reflection Factor
Flux Ratio: 80%-85%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.716	.673	.645	.708	.670	.643	.668	.643	.632
B	.799	.757	.726	.788	.751	.723	.747	.722	.711
C	.850	.810	.781	.838	.803	.778	.798	.774	.762
D	.893	.854	.826	.879	.846	.821	.839	.818	.805
E	.926	.890	.862	.908	.879	.855	.871	.850	.837
F	.363	.932	.907	.942	.919	.899	.906	.890	.876
G	.986	.960	.937	.965	.944	.927	.932	.917	.900
H	1.000	.977	.957	.978	.958	.943	.945	.932	.914
I	1.022	1.001	.984	.996	.982	.970	.967	.957	.936
J	1.032	1.014	1.000	1.005	.993	.982	.977	.968	.946

Table 12

Utilisation Factors for Lower Residual Components
Ceiling Mounted Fittings

10 per cent Floor Reflection Factor
Flux Ratio: 85%-90%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.764	.726	.701	.757	.724	.701	.721	.701	.690
B	.838	.801	.774	.828	.797	.773	.793	.771	.761
C	.882	.847	.823	.871	.840	.818	.836	.815	.804
D	.918	.885	.860	.905	.876	.855	.870	.852	.840
E	.945	.914	.891	.929	.904	.884	.896	.878	.866
F	.978	.951	.929	.959	.939	.921	.927	.913	.899
G	.998	.976	.955	.979	.960	.945	.948	.935	.919
H	1.010	.989	.971	.989	.971	.957	.958	.947	.929
I	1.030	1.011	.995	1.004	.992	.981	.978	.968	.948
J	1.036	1.022	1.009	1.012	1.002	.991	.985	.978	.956

Table 13
Utilisation Factors for Lower Residual Components
Ceiling Moulded Fittings
10 per cent Floor Reflection Factor
Flux Ratio : 90%-95%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.819	.785	.765	.811	.783	.764	.781	.764	.755
B	.878	.847	.824	.870	.842	.822	.838	.821	.812
C	.913	.884	.864	.903	.879	.861	.875	.857	.847
D	.947	.918	.896	.934	.909	.891	.904	.887	.877
E	.968	.940	.921	.958	.938	.920	.926	.912	.898
F	.993	.969	.952	.978	.959	.944	.946	.936	.922
G	1.008	.991	.973	.989	.973	.963	.964	.953	.938
H	1.018	1.001	.988	.998	.984	.972	.972	.963	.946
I	1.036	1.023	1.009	1.013	1.003	.993	.989	.981	.961
J	1.041	1.030	1.020	1.018	1.010	1.002	.994	.988	.967

Table 14
Utilisation Factors for Lower Residual Components
Ceiling Mounted Fittings
10 per cent Floor Reflection Factor
Flux Ratio : 95%-100%

Ceiling Reflection (per cent)	75			50			30		0
Wall Reflection (per cent)	50	30	10	50	30	10	30	10	0
Room Index									
A	.897	.873	.859	.891	.871	.858	.853	.858	.851
B	.933	.913	.897	.929	.909	.895	.907	.893	.887
C	.960	.938	.923	.952	.933	.918	.928	.916	.908
D	.982	.960	.945	.971	.953	.939	.948	.937	.928
E	.995	.977	.963	.984	.969	.955	.961	.951	.941
F	1.016	.996	.982	.998	.986	.974	.974	.966	.954
G	1.025	1.013	.997	1.007	.997	.988	.986	.977	.963
H	1.031	1.020	1.007	1.013	1.001	.994	.991	.983	.967
I	1.043	1.032	1.022	1.023	1.016	1.009	1.001	.995	.977
J	1.045	1.040	1.032	1.027	1.020	1.015	1.004	1.001	.980

Appendix C

Ceiling Utilisation Factors for Upper Residual Components Suspended Fittings
Wall and Floor Reflectance Nil

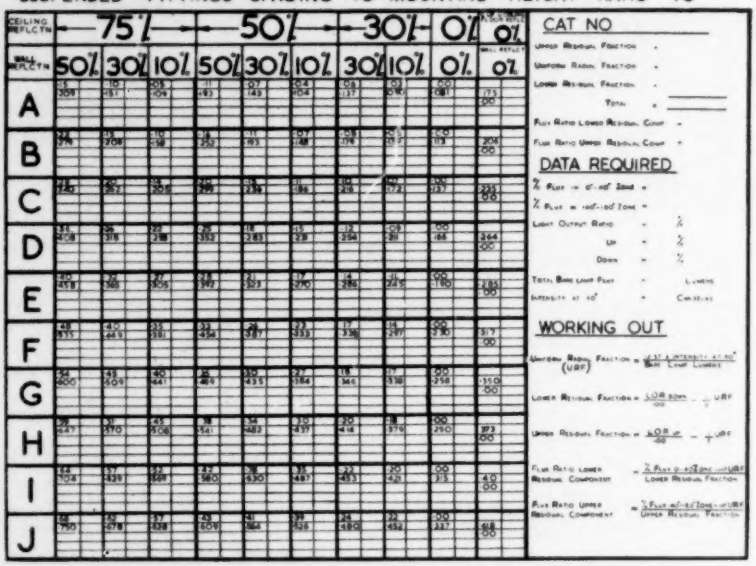
Index Room	Percentage Flux Ratios																			
	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	90-95	95-100
A	.182	.236	.291	.345	.399	.453	.503	.547	.591	.631	.666	.703	.735	.767	.815	.831	.864	.900	.948
B	.235	.291	.348	.407	.463	.520	.573	.616	.660	.697	.729	.761	.790	.815	.841	.867	.893	.922	.958
C	.295	.352	.409	.466	.523	.580	631	.682	.714	.744	.776	.803	.828	.849	.871	.892	.915	.937	.967
D	.357	.412	.468	.523	.582	.637	.687	.725	.760	.791	.817	.841	.861	.878	.897	.914	.933	.951	.974
E	.404	.457	.513	.569	.622	.678	.724	.761	.794	.820	.843	.863	.882	.897	.916	.926	.942	.959	.979
F	.483	.534	.584	.635	.689	.725	.780	.812	.839	.859	.877	.894	.909	.921	.931	.943	.956	.967	.984
G	.569	.610	.656	.699	.744	.789	.825	.851	.873	.891	.905	.915	.927	.938	.947	.957	.965	.975	.987
H	.627	.667	.708	.748	.789	.829	.869	.884	.902	.920	.929	.938	.946	.956	.962	.969	.976	.983	.992
I	.704	.735	.770	.803	.838	.871	.907	.917	.932	.944	.952	.957	.963	.971	.973	.979	.983	.985	.994
J	.747	.775	.812	.828	.869	.900	.920	.935	.951	.959	.964	.971	.973	.978	.980	.984	.987	.991	.996

Appendix D

COEFFICIENTS OF UTILISATION

SUSPENDED FITTINGS SPACING-TO-MOUNTING HEIGHT RATIO = 1·0

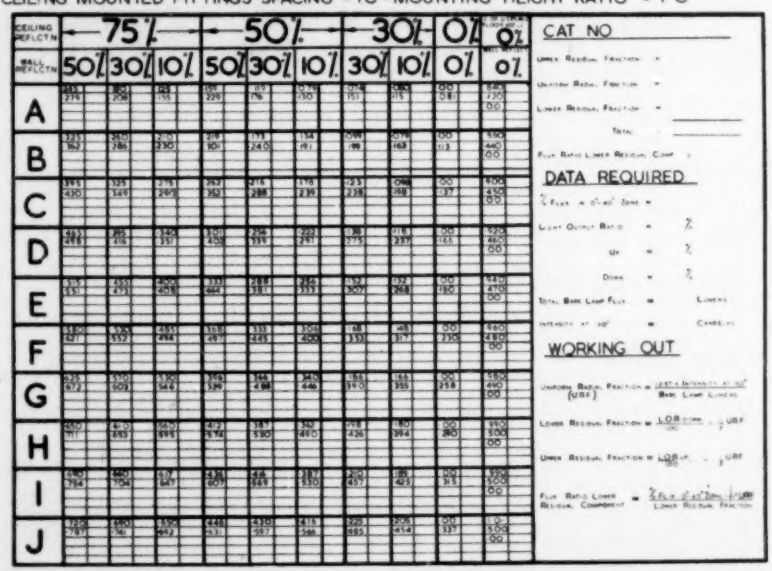
Work Sheet 1



COEFFICIENTS OF UTILISATION

CEILING MOUNTED FITTINGS SPACING-TO-MOUNTING HEIGHT RATIO = 1·0

Work Sheet 2



Appendix E

Suggested Layout of Results

COEFFICIENTS OF UTILISATION

TABLE FOR FITTING NO. DATE:

FLOOR REFLCTN	10%									L	M
CEILING REFLCTN	75%			50%			30%			0%	0%
WALL REFLCTN	50%	30%	10%	50%	30%	10%	30%	10%	0%	0%	0%
ROOM INDEX	ROOM RATIO	COEFFICIENTS OF UTILISATION									
		WORKING PLANE									CEILING
A	·6										
B	·8										
C	1·0										
D	1·25										
E	1·5										
F	2·0										
G	2·5										
H	3·0										
I	4·0										
J	5·0										

Appendix F

Calculation of the Zonal Flux for Upper Residual Components with Low Flux Percentages

Let I_{180} = Intensity of upper residual component at 180° to the downward vertical.

I_θ = Intensity of upper residual component at any angle θ between 90° and 180° to the downward vertical.

Consider the equation,

$$I_\theta = I_{180} \cos^n \theta \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where values of cos θ are taken to be positive. When $n=0$, the flux ratio is approximately 23 per cent and to obtain smaller values than this n has to be negative, which makes the intensity at 90° infinite. However, low flux ratios can be obtained by taking the difference between two curves which are of the form of equation (1), but have different values of n.

Let P = desired flux ratio.

L and M = flux ratio of the two curves to be combined, where L is greater than M.

then $P = \dfrac{L - rM}{1 - r}$ where r is to be found.

therefore,

$$r = \frac{L - P}{M - P}$$

Thus, if L = 32.5 and M = 27.5,

$$r = \frac{32.5 - P}{27.5 - P}$$

Suppose it is required to find a distribution with a flux ratio of 7.5, that is, P = 7.5,

$$\text{then } r = \frac{32.5 - 7.5}{27.5 - 7.5}$$

$$= 1.25$$

and therefore

$$P = \frac{L - 1.25M}{-0.25}$$

$$= 5M - 4L$$

Thus to find the flux in any zone of the new curve, 4 times the zonal flux of curve L is subtracted from 5 times the zonal flux of M. The new curve will then have 7.5 per cent of its flux in the 140°-180° zone.

This procedure can be repeated to find curves with flux ratios from 12.5 to 22.5. Unfortunately, the method fails for a flux percentage of 2.5, since the zonal lumens in the first few zones become negative.

I.E.S. Gold Medal

At the opening meeting of the 1959-60 session of the Society held in London on October 13, Mr. C. C. Smith, the retiring President, made the first award of the I.E.S. Gold Medal when he presented it to Dr. J. W. T. Walsh.

Mr. Smith recalled that the medal had been instituted to mark the occasion of the Society's Golden Jubilee; he also recalled the regulations governing the award, viz., that it should be bestowed for outstanding contributions to the advancement of lighting, the medal to be awarded at intervals of not less than two years, and that recipients may be of any nationality and may or may not be members of the Society. Mr. Smith pointed out that under such terms the Council had the widest possible choice in selecting those whose contributions to the advancement of lighting it wished to acknowledge in this way. Dr. Walsh was an Honorary Member and had twice been President of the Society; the award of the Gold Medal, however, was in recognition of Dr. Walsh's many contributions to lighting over a long period.

The President then presented the medal to Dr. Walsh, who said: Mr. President, ladies and gentlemen, from the moment I had the first intimation of this presentation at the recent Council Meeting to which you, Mr. President, have referred, I have been trying hard to think of some words that would adequately express my appreciation of this great honour which the Society has done me. I now realise I cannot convey to you my feelings in the matter.

I have been a member of the Society a good many years and I owe it a tremendous debt of gratitude, not only for the honours which it has conferred upon me in its kindness, but also for a number of other things, for all that I have learnt from my fellow members and for the great and valued friendships which I have formed within the Society's ranks. I may say, sir, that when I retired some years ago I made up my mind that nothing would induce me to cut myself off from the Society to which I owed so much and it has been a very great joy to me to witness its steady growth and the increase of its influence with the passing of the years.

I should like to take this opportunity of congratulating the Society on the announcement which has just been made (the election of H.R.H. The Duke of Edinburgh as an Honorary Fellow). I think this is a wonderful and, I believe, a well deserved recognition of the work which the Society has done during the half century of its existence. I think we may all feel more than delighted at this recognition which has come to us from the Royal House.

In conclusion, let me say again "thank you all very much indeed" for this great and, I feel, quite undeserved honour that you have conferred on me.

UDC 612.843.367

Practical Application of Direct Discomfort Glare Research in the New Australian Artificial Lighting Code

By J. C. LOWSON, B.E., A.M.I.E.E., F.I.E.S. (Aust) (*Fellow*).*

Summary

Practical lighting design has hitherto been seriously handicapped by the meagre amount of quantitative data on discomfort glare in most current lighting codes and handbooks. Much valuable fundamental information about glare is available, but before this knowledge can be transferred from the laboratory notebook to the lighting design handbook it must be converted into a form simple enough for the practising lighting engineer to use at the drawingboard stage of design, and it is with the solution of this and related problems that the present paper is primarily concerned. It is shown that by taking a realistic view of the accuracy required when specifying permissible luminance limits for general lighting luminaires, it is possible to devise a tabular method of specifying such limits which is exceedingly quick and simple to apply, yet subtle enough to take reasonable account of the known facts about glare. This new table of recommended luminance limits (for diffusing luminaires and bare fluorescent lamps used for evenly distributed general lighting in work places) has been incorporated in the new artificial lighting code (A.S. No. CA.30) recently published by the Standards Association of Australia.

(1) Introduction

As is well known, the brightness of interior lighting units must be suitably controlled if direct glare is to be kept within bounds ; but the formulation of practical rules to help the lighting designer choose an appropriate luminance limit is by no means easy.

There is, in fact, a two-fold problem. On one hand, the rules must take into account a number of fairly complicated contributory factors, such as the number and the apparent size of the potential glare sources, their position in the field of view and the general background luminance to which the eye is adapted. But on the other hand these same rules must not be too complicated. Practising lighting designers do not usually have the time for lengthy computations or elaborate graphical construction ; unless a design method is simple and straightforward enough for everyday use its practical value is very limited.

The intensive quantitative research on glare that has been going on throughout the world during the last ten years or so has provided a considerable amount of fundamental information concerning the nature of glare and a variety of "glare formulae" have been proposed—such as the one suggested by Hopkinson at the 1955 C.I.E. meeting(1). But the problem of converting such formulae into practical design rules has been much less fully explored and so far only one really promising scheme has been described, namely the tabular method developed by Ward Harrison and Phelps Meaker(2).

However, even this system is not simple enough to use in a code and, when searching for a method of applying modern knowledge of glare in the new revised artificial lighting Code published by the Standards Association of Australia(3), considerable work had to be done before a satisfactory method of presentation could be developed.

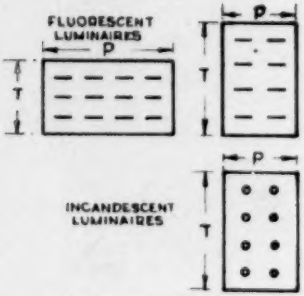
The object of the present paper is to explain this new method, and to show that in spite of its comparative simplicity it is subtle enough to take reasonable account of the known facts about glare control.

It should be noted that since this work was a contribution to the preparation of an S.A.A. code the scheme has naturally been reviewed by many people through the Commonwealth of Australia. It is impossible for the author to mention all those who have made helpful comments and suggestions since the basic idea was first proposed. However, particular reference should at least be made to the members of the original S.A.A. Code Drafting

* The author is with the Commonwealth Department of Labour and National Service, Melbourne. The manuscript of this paper, which is based on a lecture presented during the 31st Meeting of the Australian and New Zealand Association for the Advancement of Science in Melbourne, August, 1955, was first received on December 30, 1957, and in final form on June 11, 1959.

DETERMINATION OF "h".

DETERMINATION OF "T" AND "P".



ROOM DIMENSION "T"	ROOM DIMENSION "P" 2h	3h	4h	5h	6h	7h	8h	10h	12h	14h
2h	6	6	6	6	4	4	4	4	4	4
3h	4	3	3	3	3	3	3	2	2	2
4h	3	2	2	2	2	1½	1½	1½	1½	1½
5h	2	1½	1½	1½	1½	1½	1½	1	1	1
6h	1½	1½	1	1	1	1	1	1	1	1
7h	1½	1	1	1	1	1	1	1	1	1
8h	1½	1	1	1	1	1	1	1	1	1
10h	1	1	1	1	1	½	½	½	½	½
12h	1	1	1	½	½	½	½	½	½	½
14h	1	1	½	½	½	½	½	½	½	½

METHOD OF USE. The appropriate luminance limit is found at the intersection of the nearest "P" column and "T" row on the table, "P" and "T" being the dimensions of the room expressed as multiples of "h" the mounting height of the luminaires above eye level.

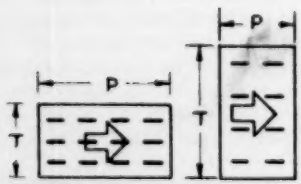
For installations of elongated units mounted horizontally (e.g. ordinary fluorescent lamp equipment)—

"P" will be the room dimension parallel to the lamp axes (regardless of whether this is the longer or shorter dimension of the room).

"T" will be the transverse dimension (see sketches below).

For all other installations—

"P" will be the shorter and "T" the longer dimension of the room.



ROOM DIMENSION "T"	ROOM DIMENSION "P" 2h	3h	4h	5h	6h	7h	8h	10h	12h	14h
3h	8	8	6	6	6	6	6	6	6	6
4h	8	6	6	4	4	4	4	4	4	4
5h	6	6	4	4	4	4	4	4	4	4
6h	6	4	4	3	3	3	3	3	3	3
7h	6	4	3	3	3	3	3	3	3	3
8h	4	3	3	3	3	3	3	3	3	3
10h	3	3	3	2	2	2	2	2	2	2

AUXILIARY TABLE OF LUMINANCE LIMITS. For use in the special case where all occupants of the room consistently work facing in a direction parallel to the axes of tubular fluorescent lamp units (i.e. facing in the direction indicated by the arrows on the sketches left), and thus view the luminaires end-on rather than broadside-on when they raise their eyes from their work.

Fig.1. Recommended permissible luminance limits for diffusing units and bare fluorescent lamps used for evenly distributed general lighting in work places. (Luminance values are expressed in cd/in² and are measured as described in Section 4.)

Panel in Sydney; namely, Mr. F. Brown (Chairman), Mr. W. I. Stewart (Secretary), Mr. J. S. Johnson, and Mr. S. Holman, who helped to steer the project through its early formative stages; and above all to the author's colleague, Dr. A. Dresler, who has been closely associated with the project throughout.

(2) The S.A.A. Code Glare Tables

The new tables and their method of use are explained in Fig. 1. The tabulated limits are in candelas per sq. in. and refer to the luminance of general lighting luminaires measured in one specific direction, namely at 70 deg. to the downward vertical and broadside on to the unit in the case of fluorescent or other elongated units mounted horizontally.

The significant luminance is the average figure obtained by dividing the luminous intensity in the single specified direction by the projected area of the luminous parts of the unit. The procedure, which is of course the responsibility of the lighting equipment manufacturer rather than the code user, will be discussed in more detail in Section 4.

The tables in Fig. 1 are a very slightly simplified version of those used in the S.A.A. Artificial Lighting Code. Some examples illustrating their use are given in Appendix 1.

(2.1) Luminance limits employed

The tables are based on a range of eight luminance limits; namely ½, 1, 1½, 2, 3, 4, 6 and 8 cd/in^2. This subdivision of the range into a series of finite, fairly wide steps roughly evenly spaced on a logarithmic scale is a very important feature of the new method. This approach makes it legitimate to ignore factors which do not affect the issue by more than ±15-20 per cent and, as will be shown later, this makes possible a number of useful short-cuts and approximations which have greatly simplified the final tables.

Another major practical advantage is that this division of the range into wide steps—or "luminance groups" as it is convenient to call them—makes it easy for the lighting equipment manufacturer to supply relevant data on his products. Fig. 2 sets out this system of luminance groups and indicates a few of the typical luminaires belonging to them.

It is interesting to compare this range of luminance limits with that used in the previous edition of the Australian lighting code[4], the relevant provisions of which are shown in Fig. 3. This range was made obsolete by the advent of the fluorescent lamp; for one thing it did not go high enough to take in bare tube units. This point is illustrated in Fig. 4 where it will be seen that the new set of limits brackets the old. It may be mentioned in passing that although the old range did not influence in any way the choice of the new one there is remarkably close agreement between them for average size rooms.

(2.2) Scope of tables

The tables are not intended to apply to open type luminaires in which glare is controlled solely with opaque shades and louvres. These are catered for in the Code by means of a shielding angle table of more or less conventional type.

However, units employing both shielding and diffusion to control glare (e.g. louvred luminaires with diffusing sides) are expected to comply with the luminance limit table as well as the shielding angle table. This point will be dealt with in more detail in Section 4.

The tables also apply to units in which bare fluorescent lamps are exposed to view at and above 70 deg. to the downward vertical.

It should be particularly noted that the tables in Fig. 1 only apply to general lighting luminaires used in workplaces. They do not apply to interiors where there are no critical visual tasks to be performed and where people only spend short periods.

The question of whether exposure to glare is short or long, i.e. a matter of minutes or some hours at a time, is of considerable practical importance since discomfort glare is cumulative in its effect. In this it resembles other discomfort phenomena—a hard bench, for instance, is comfortable enough to sit upon for a few minutes but not for long periods. Similarly, lamps or luminaires which do not appear at a casual glance to have an uncomfortably high luminance can actually cause serious inconvenience to the occupants of an office, say, who have them in their field of view every time they raise their eyes from their work.

Here it may be noted in passing that the cumulative discomfort produced by a very slightly glaring lighting installation makes it far more important to take precautions against discomfort glare than against disability glare, which is not cumulative in its effect. Experience suggests that in normal well-designed general lighting installations for working interiors, if discomfort glare can be adequately controlled, disability glare will take care of itself.

(3) Basis of the Tables

As is well known, the principal physical factors governing the degree of discomfort produced by

TYPICAL FLUORESCENT EQUIPMENT. In every case it is assumed that lamps are the normal high-efficiency variety; and any diffusing material used is presumed to be of good quality.

GROUP	LUMINANCE* (cd/sq. in.)	Typical fluorescent equipment
H	Not over 8 but over 6	5 ft. 80W 1½" dia. 'hot-cathode' bare lamp units 8 ft. 70W 1" dia. 'slimline' " " "
G	" 6 " 4	4 ft. 40W 1½" dia. 'hot-cathode' bare lamp units 8 ft. 75W 1" dia. 'slimline' " " "
F	" 4 " 3	8 ft. 50W 1" dia. 'cold-cathode' bare lamp units 2 ft. 20W 1½" dia. 'hot-cathode' " " "
E	" 3 " 2	2 X 40W 4 ft. totally enclosed diffusing units 2 X 40W, or 3 X 40W 4 ft. units with longitudinal louvres made of diffusing material.
D	" 2 " 1½	
C	" 1½ " 1	Cut-off units with opaque sides or louvres. Luminous ceilings; and louvred ceilings made of opaque or highly diffusing material.
B	" 1 " ½	
A	Not over ½ cd/sq. in.	

* The luminance figures quoted refer to an average value measured at 20° below the horizontal, and normal to the lamp axis in the case of fluorescent units.

TYPICAL INCANDESCENT EQUIPMENT. All units are of the totally enclosed, general diffusing type made of good quality opal glass. The shape, overall diameter, and lamp wattage is indicated in each case.

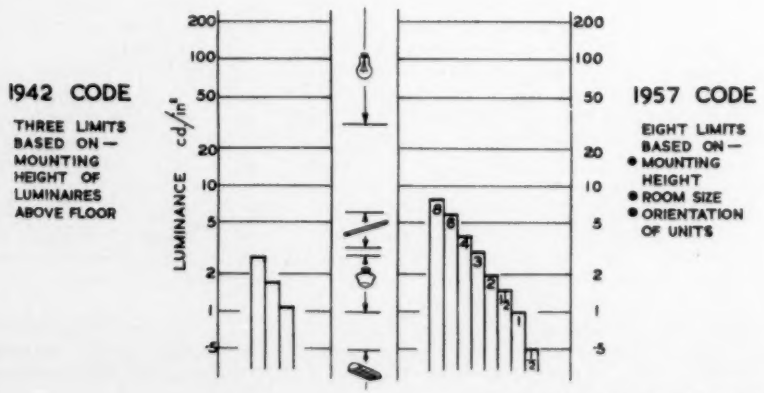
8" dia	10" dia	12" dia	14" dia	16" dia	18" dia
-	200W	-	-	300W	500W
100W	150W	200W	200W	-	300W
75W	100W	150W	150W	200W	-
60W	75W	100W	-	150W	-

Fig.2 (*above*). *System of broad luminance groups based on the set of eight fixed luminance limits, together with a few representative examples of luminaires belonging in various groups.*

Mounting Height Above Floor	Luminance cd/in²
Below 9 ft.	1.1
9 ft.-14 ft.	1.8
Above 14 ft.	2.7

Fig.3 (*right*). *Luminance limits recommended in the 1942 S.A.A. artificial lighting code for general diffusing luminaires used in offices and locations where continuous close seeing work is performed.*

Fig.4 (*below*). *Comparison between the luminance limit systems of the 1942 and 1957 editions of the S.A.A. artificial lighting code.*



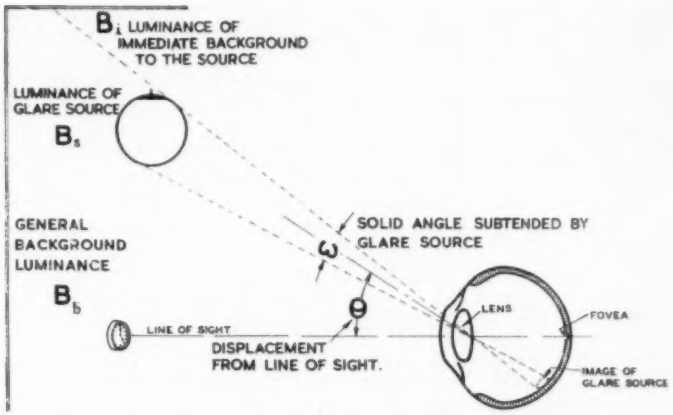


Fig.5. Principal factors influencing the degree of discomfort produced by a glaring luminaire in the field of view.

In this very simplified diagram of the eye, the lens is shown forming an image on the fovea of the object upon which the gaze is fixed, and at the same time forming an image of the glaring luminaire at another point on the retina.
Discomfort produced by the glaring luminaire will be greatest

(*a*) when its image on the retina approaches close to the fovea (i.e. when θ the angular displacement of the glare source from the line of sight is small);

(*b*) when the image is large (i.e. when the solid angle ω subtended by the luminaire at the eye is large, or when there are numerous luminaires in the field of view);

(*c*) when the flux per unit area over the image is large compared with the flux per unit area over the rest of the retina (i.e. when B_s is large compared with B_b).

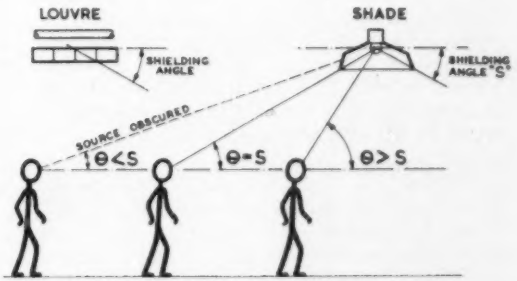


Fig.6. Glare control by shielding. Shades and louvres conceal the lamp whenever displacement angle θ is less than shielding angle S.

a glaring luminaire are B_s, the luminance of the glare source ; ω, the solid angle subtended at the eye ; θ, the angular displacement from the line of sight ; B_b, the general background luminance ; and B_i, the luminance of the immediate surroundings of the glare source. The part that these various factors play is illustrated diagrammatically in Fig. 5.

Of the abovementioned factors, angular displacement θ has perhaps the greatest general importance. If θ is more than about 45 deg. glare will not normally be serious (unless the glare source is a powerful high brightness lamp hanging fairly low down near eye-level). On the other hand, if θ is less than about 20 deg., even a comparatively low brightness source, such as a bare fluorescent tube, can cause considerable glare if persons are exposed to it over a period of time.

In practice, therefore, direct glare may be kept within bounds either by using shades and louvres to hide the lamp completely whenever the luminaire containing it approaches too close to the line of sight (see Fig. 6) or else by using translucent diffusing material to limit B_s when angle θ is small (in other words, to limit the side brightness of the luminaires).

Of these two basic methods the first is the simpler to legislate for in a code. Once cut-off

has taken place, the luminance of the still visible portions of the unit is generally too low to cause serious glare, even when the interior is large and the field of view takes in many units.

Consequently, it is possible to draw up a fairly simple set of empirical shielding angles which take into account the degree of glare control required and the type of lamp used. In Australian practice three standard shielding angles are recognised for general lighting luminaires, *viz.*, 20 deg., 30 deg. and 45 deg. and recommendations regarding the choice of angle will be found in the current S.A.A. Artificial Lighting Code(3).

In the case of non cut-off luminaires, however, the problem is much less simple for here the precise value of B_s that will give adequate glare control in a given installation depends on the value of the other factors and it is necessary to combine then into " glare formula " of the form

$$G = \frac{B_s^m}{B_b^p} \cdot \omega^n \cdot f(\theta) \cdot f(B_l)$$

where G is a numerical quantity related to the discomfort produced and quantities B_s, ω and B_b are weighted with numerical exponents m, n and p to allow for their relative importance. Considerable research has gone into determination of the exponents and functions in this equation. The classic investigation by Holladay published in 1926(5) was one of the first attempts to fill in the unknowns and during the last 30 years, particularly the last ten or so, much of the published research on glare in America, Britain and Europe has been directed at the determination of suitable values for the unknowns in this expression.

Since this work has been extensively reported(1, 6), it need not be reviewed in detail here. However, it may be worth mentioning that Holladay's investigation indicated that the exponent on B_s was probably about four times that on ω, and this led to a popular belief at the time (particularly amongst American lighting engineers) that as a practical design expedient one could afford to ignore the area of the glare source entirely and rely on luminance ratios alone as a means of ensuring comfort.

The idea that glare source area is of negligible importance was subsequently shown to be a fallacy—the point being that the relationships determined by Holladay in his laboratory work with small glare sources (ω=.001 steradian or less) do not apply in practical installations where the aggregate value of ω usually lies in a range of about 0.008 to 0.30 steradian(7). (See Fig. 7.)

However, long before the point was finally resolved by the measurements of Luckiesh and Guth published in 1949(8), Ward Harrison had been expressing doubts about the wisdom of ignoring source area and in 1945 he introduced his first " Glare Factor " formula in which the exponent on B_s was twice that on ω(9).

This variant of Holladay's original formula was largely empirical and was based, as Ward Harrison has put it, on " incomplete laboratory data . . . supplemented by considerable experience of qualified engineers "(10). It may be noted in passing that although this method of approach was coldly received at the time, subsequent events have shown that this same " strange mixture of theory and guesses " (as one critic of the 1945

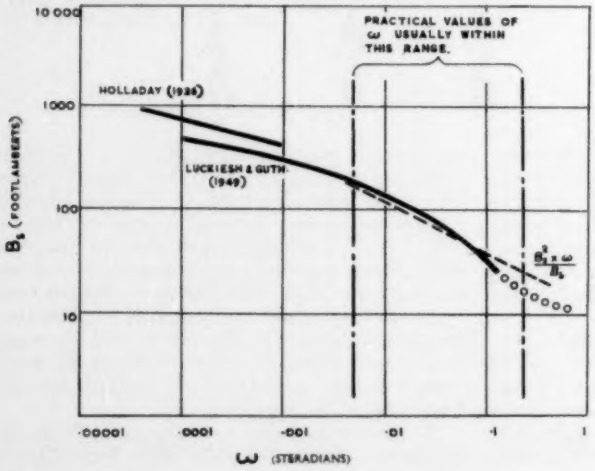


Fig.7. Variations in B_s required to keep glare constant when ω changes (B_b=1 ft-L).

paper put it) actually represented a major step forward in the struggle to find a way of setting realistic luminance limits.

(3.1) The Harrison-Meaker formula

In 1947 Ward Harrison in collaboration with Phelps Meaker published a slightly amended version of the 1945 formula in which exponents on B_s, ω and B_b were 2, 1 and 0.6 respectively. These agree remarkably closely with the exponents which research laboratory work has since shown to be suitable for use as a working approximation and which are embodied in the formula proposed by Hopkinson[11] and put forward at the 1955 C.I.E. meeting, where :

$$G \propto \frac{B_s^2 \cdot \omega}{B_b}$$

The only important difference is the exponent of 0.6 attached to B_b. This low exponent was employed by Ward Harrison to allow for his observation that, if the illumination level in an installation is increased by introducing more and more luminaires of the same fixed luminance, the discomfort glare will also increase. This point is explained in more detail in Appendix 2 where it is shown that, considering the ± 20 per cent limits of accuracy in which we are interested, a correction for illumination level seems hardly necessary. Consequently, for the purposes of the Australian code, the H.-M. correction factor for illumination level was dropped, which had the effect of converting this part of the Harrison-Meaker formula into the currently accepted $\frac{B_s^2 \cdot \omega}{B_b}$ form.

However, as explained in the next section, application of even the simplest formula presents serious practical difficulties and the main attraction of the Harrison-Meaker proposal was their system of precalculated " glare tables " which enable data of this kind to be transferred from the laboratory notebook to the practical design handbook.

(3.2) Importance of tabular presentation

However simple and accurate they may be, glare formulae in their raw state are not of very much use to the busy practising lighting engineer who has neither the time nor the equipment needed to estimate individual formula factors in advance. To estimate ω, for instance, it would be necessary to draw an elaborate perspective sketch for each proposed installation and then laboriously planimeter the outlines of the luminaires. Something far quicker and simpler is needed before the basic information in a glare formula can be applied in practice. In other words, the data must be predigested and presented in the form of tables, preferably no more complicated than the familiar " Coefficient of Utilisation " tables.

As already mentioned, the first successful attack on this important problem was made by Ward Harrison and Phelps Meaker who presented a system of glare factor tables in their 1947 paper[3]. Here the formula is used to calculate the glare factor from the " worst view-point " (i.e. from the viewpoint of an observer placed where he will have the maximum aggregate area of glare source in his field of view when looking horizontally across the room). The numerical glare factors produced by installations of a given type of luminaire are calculated for a series of rooms of varying shape and size ranging from small rooms with only a few luminaires within the field of view, to large rooms with many such luminaires. Glare factors associated with the chosen type of luminaire are then tabulated against dimensions of the room and the mounting height of the units so that at any future time when an installation of this type of luminaire is contemplated, one need only know the dimensions of the room and mounting height of the units in order to read off the approximate Harrison-Meaker glare factor of the installation from the appropriate table. (It should be noted that tables of this kind can be greatly compressed by expressing room dimensions in terms of "h", the mounting height above eye-level. This idea was introduced in the original 1947 Harrison-Meaker paper but not used again.)

The fact that the degree of glare depends more upon the room proportions than upon its actual dimensions is illustrated diagrammatically in Fig. 8. This shows cross-sections of two rooms superimposed upon one another, the dotted outline indicating a small room and the full outline a larger room in which both the mounting height above eye level " h " and the room length (and width) have been increased in about the same proportion so that the length of the room expressed in multiples of " h " remains approximately the same. The luminaires are assumed to be of the same size and luminance in each case, so that their number has had to be increased in the larger room in order to produce the same illumination level. It will be noted that, from the observer's point of view, the luminaires are still all contained within the same solid angle and though there are more units in the larger room this is counter-balanced by the fact that they are further from the observer's eye. Hence the total solid angle subtended by the glare sources at the observer's eye is approximately unaltered and (since other

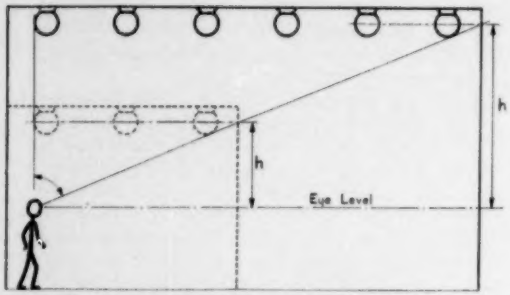


Fig.8. Luminance limits can be related to room dimensions expressed as multiples of "h," the mounting height above eye level. If this proportion does not change, the mean values of ω, θ and B_b will remain approximately constant too.

factors are much the same in both cases) the degree of discomfort glare will remain approximately unaltered too.

(3.3) Validity of the Harrison-Meaker tabular method

In spite of the many approximations and simplifications inherent in this approach, it does in fact seem to work quite well in practice, as was shown by a field test carried out by the Illuminating Engineering Society of Australia (N.S.W.) in Sydney some time ago when the Harrison-Meaker method was first being considered as a basis for the glare recommendations in the S.A.A. Code.

One rather important point which was insufficiently stressed in the published account of these tests[12] is that when working out the glare factors of the various test installations, no attempt was made to analyse the glare produced by individual luminaires. Instead, calculations were based solely on the easily ascertainable quantities of room length and width, luminaire mounting height, the luminance of the typical luminaire measured from a single standard direction, and the illumination level. From this data, Harrison-Meaker glare factors were calculated by graphical interpolation on one or two of the original Harrison-Meaker tables (actually those relating to spherical diffusing luminaires and to bare fluorescent lamps used crosswise and endwise) suitable allowance being made for the difference between the luminances measured and those referred to in the Harrison-Meaker tables. Results are summarised in Fig. 9.

Considering the short-cut approximations and simplifications on which the tabular method is based, the excellent results achieved in this test were exceedingly encouraging, for they suggested that worthwhile results could be achieved by methods simple enough for the lighting designer to use in his everyday work.

Here it may perhaps be mentioned in passing that an almost equally important aspect of the tests was the moral effect they produced on the observers. Even though the glare factors had not yet been calculated, mere participation in the series firmly convinced these lighting engineeers of the practical importance of the factors taken into account by the tables. In view of this, some practical suggestions on how to make observations of this kind are given in Appendix 3.

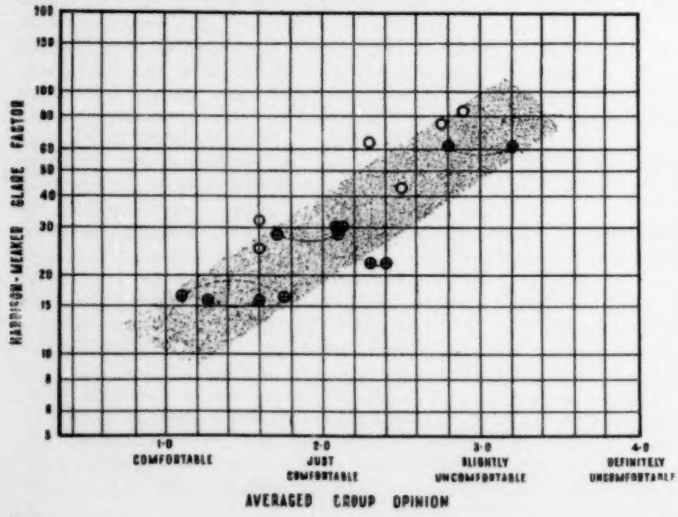


Fig.9. The Sydney glare appraisal tests. Note that each point on the chart represents the averaged independent opinions of the members of one group of four or five observers. Where two such groups appraised the same test installation the relevant pair of points have been linked by a dotted line.

(3.4) Drawbacks of the Harrison-Meaker tables

Useful as they are, the Harrison-Meaker tables do not supply the complete answer to the problem of presenting data in a conveniently usable form, especially when it comes to laying down rules and recommendations in a code. For one thing, they only apply to a single type of luminaire of given luminance; and although they give detailed information about the degree of glare produced in various shapes and sizes of rooms it seems reasonable to suppose that the ordinary lighting engineer is more interested in making sure that a proposed installation is not unduly glaring than in finding out what the particular glare factor will be, and would willingly sacrifice the latter refinement for the sake of a more universally applicable table giving the maximum permissible luminance that can be used in the given circumstances.

(3.5) Derivation of the S.A.A. Code tables

In preparing the S.A.A. Code tables the above-mentioned drawbacks were overcome by "turning the Harrison-Meaker tables inside out." Instead of tabulating varying glare factors for a fixed luminaire luminance the new tables indicate the maximum luminaire luminance which can be permitted if the glare factor is not to exceed a certain figure taken as a boundary line between comfort and discomfort.

The data summarised in Fig. 9, studied in the light of a critical survey of the Luckiesh-Guth BCD proposals, by J. S. Johnson, eventually led to the choice of 40 as the limiting glare factor to be used in practical design.

The tables shown in Fig. 1 are based on the Harrison-Meaker tables for general diffusing globes and for bare fluorescent tubes (endwise view), i.e. on Tables 1 and 2 of their 1947 paper.

These are converted from tables of varying glare factors for a fixed luminaire luminance into tables of varying luminance for a fixed glare factor of 40 by means of the following formula:

$$\text{Permissible Luminance} = \frac{B_t \times 40}{G_t \times 0.7}$$

where

B_t is the fixed luminaire luminance assumed when plotting the original Harrison-Meaker table.

G_t the tabulated glare factor.

The factor G_t is multiplied by 0.7 to convert it into a value suitable for a 15 lm/ft² illumination level, for when the S.A.A. tables were first planned it was intended to make them apply to installations in the 10 to 25 lm/ft² range, and to recommend one step reduction in luminance above this range with one step increase in luminance below it. However, for reasons given in Appendix 2, the allowance for illumination level was subsequently found to be an unnecessary complication and was consequently dropped.

Since the H.-M. formula states that G is proportional to $\frac{B_s^2 \cdot \omega}{B_b^{0.6}}$ it may at first sight seem strange that the glare factor should be proportional to B rather than B_s^2 in the conversion formula. However, a moment's consideration will show that this is quite correct, the essential point being that since the Harrison-Meaker tables are calculated for a specified illumination level (i.e. for a constant value of B_b), any increase in B_s must be counterbalanced by a proportional reduction in the value of ω.

(3.5.1) *Justifiable simplifications*

A major simplification was made possible by the discovery that even in long narrow rooms maximum glare is likely to be experienced when observers view rows of fluorescent luminaires broadside on, no matter whether the luminaires are orientated along or across the room. This enabled some rather complicated instructions based on the observer's line of sight to be eliminated and replaced by the present comparatively simple instructions given in Fig. 1.

It was also found unnecessary to differentiate between fluorescent and incandescent installations in spite of the fact that projected area of the elongated source varies depending on the azimuthal angle of view, whereas the projected area of the incandescent unit does not. Glare diminishes rapidly when sources are displaced more than about 45 deg. from the line of sight; and by the time a unit is displaced far enough to the side for the projected area to be appreciably reduced by foreshortening, its individual contribution to the total glare will be very small. This meant that an originally proposed additional table covering incandescent luminaires could be dropped. This was yet another important simplification made possible by taking a realistic view of the accuracy required.

(3.5.2) *An important special case*

Special allowance had, however, to be made in the case of installations where all the occupants of the room work facing parallel to the axes of fluorescent luminaires and thus always see them more or less end-on when they raise their eyes from their work.

Under these circumstances the potential glare is greatly reduced not only by the reduction in

projected area, but also by the reduction in luminance.

The extent of this can be gauged by applying the formula $G \propto \frac{B_a^2 \cdot \omega}{B_q}$ to the case of a bare fluorescent lamp viewed first broadside on, and then at an angle of 20 deg. to the long axis, other factors remaining the same. In the second case, the projected area will drop to 35 per cent, and the luminance to about 60 per cent of the values obtained when the lamp is viewed broadside on.

Thus, if B_a, ω and B_b are all unity (so that their combined effect is unity also) ; viewing the lamp at 20 deg. to the axis and keeping all other variables constant will cause the comparable glare factor to drop to $\frac{(0.6)^2 \times .35}{1}$ i.e. to about one-eighth of that obtained when the lamp is viewed broadside on. Design limits based on the latter view are consequently unreasonably stringent when applied to interiors where one can be sure that all occupants will work facing in a direction parallel to the axes of the lamps and will thus seldom or never see them broadside on. The auxiliary Table in Fig. 1 is therefore needed to cater for this special case.

(3.5.3) *General applicability of the tables*

One point which must be briefly examined is the validity of applying tables based on diffusing units with uncontrolled distribution, to all luminaires incorporating diffusing materials, as explained in Section 2.2.

To cite an extreme case, it is obvious that in an installation of luminaires incorporating three or four fluorescent lamps, say, with an eggcrate louvred bottom and only comparatively small diffusing side panels the balance between the quantities in the basic formula would be quite different, the aggregate value of ω, for instance, being appreciably smaller for a given value of B_b.

However, it must be remembered that luminaires with an uncontrolled distribution represent the worst case ; moreover, since the translucent panels in the type of luminaire mentioned above are usually mainly decorative, conformity with luminance limits designed to suit luminaires with uncontrolled distribution presents no particular difficulty.

In the circumstances there does not seem any great practical advantage to be gained at this stage by increasing the number of tables beyond the two basic ones proposed.

(3.6) Relation to the basic physical factors

In practical lighting design it is by no means easy to allow directly for the basic factors such as apparent size and position of the glare sources. However, it appears possible to make adequate allowance for these factors by taking account of such readily available data as room size, mounting height and so on. Fig. 10 illustrates this point.

(4) Measurement of Luminance

It is obvious that the practical success of any system of luminance limits depends on the availability of luminance data on actual luminaires. It is therefore vitally important to employ a method which, though sufficiently accurate, is yet sufficiently simple for any manufacturer to use.

These considerations have governed the choice of method specified in the S.A.A. Code, which is essentially as follows :

(*a*) The significant luminance is measured at 70 deg. to the downward vertical, and normal to the axis of the unit in the case of fluorescent, or other horizontally elongated luminaires.

(*b*) It is determined by measuring the mean candlepower in the specified direction and then dividing this by the projected area of *either* the translucent luminous parts of the luminaire, if these provide adequate diffusion ; *or* the lamps themselves, in the case of bare lamp units and units incorporating materials providing inadequate diffusion.

(*c*) Materials providing inadequate diffusion are defined as those which when viewed from the critical direction do not appreciably reduce the maximum luminance of the luminaire below that of the lamp which it contains, i.e. material through which the outline of the lighted lamp is discernible, or clear material with a figured surface which merely distorts the shape of the lamp behind it.

(*d*) Lighting equipment manufacturers need not quote the precise luminance figure. All they have to do is state the luminance group (A-H) in which the units belong. (See Fig. 11.)

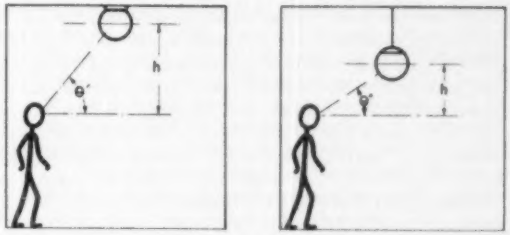
Some notes on the above points are given below.

(4.1) Direction of measurement

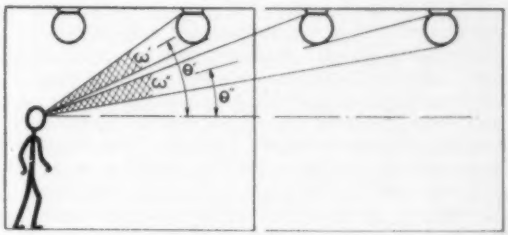
Luminances at all angles of view between the horizontal and about 45 deg. below the horizontal are theoretically significant, but bearing in mind that we are only attempting an accuracy of about ± 20 per cent, a luminance reading in a single standard direction is yet another justifiable simplification. Some reasons for this are as follows.

Fig.10. Summary of the basic principles underlying the new luminance limit tables.

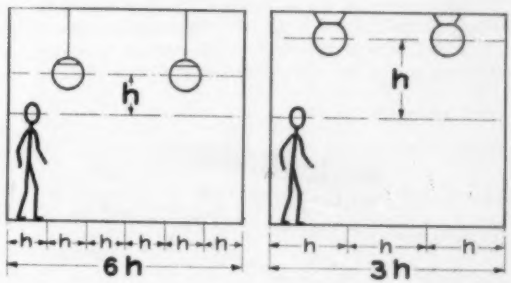
Reducing "h" the mounting height above eye-level reduces the mean value of θ. To prevent a consequent increase in glare, B_s must therefore be reduced as well. Hence the tables set a lower luminance limit when "h" is reduced.



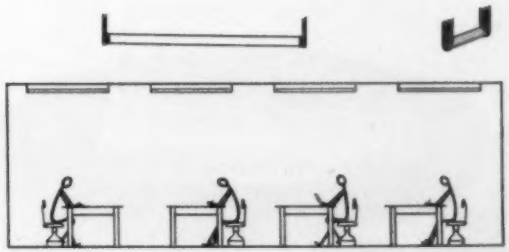
Increasing the room dimensions increases the total value of ω and also reduces the mean value of θ. To balance this, B_s must be reduced. Hence the tables set lower luminance limits in larger rooms.



The combined effect of mounting height and room size can be allowed for by expressing the room dimensions in terms of "h," and in the tables the luminance limit is determined in this way.



When elongated luminaires are viewed obliquely, ω and B_s are both reduced. Such units thus cause much less glare when viewed end-on rather than broadside-on. If desks, etc., can be so arranged that occupants normally view luminaires in this way, units of a given specified luminance can be used in larger rooms and at lower mounting heights than would otherwise be possible. The auxiliary table caters for this special case.



The changes in luminance (and apparent area) which occur when fluorescent units are viewed in azimuthal planes other than that normal to the lamp axis, can be estimated in advance and are in fact taken into account by the tables in Fig. 1. Moreover, in the plane normal to the axis of the lamp the luminance of the translucent luminous parts of ordinary well-designed luminaires does not usually alter very greatly throughout the critical zone, i.e. between the horizontal and about 45 deg. below the horizontal. A single reading at 20 deg. below the horizontal (i.e. somewhere about the middle of the significant zone) will therefore be sufficiently accurate in the majority of cases.

One obvious exception is the translucent trough reflector unit with a shielding angle only slightly greater than 20 deg. However, this case is taken care of in the Australian code by specifying that luminaires employing both shielding and diffusion to control glare must also comply with the standard minimum shielding angle provisions. The translucent trough reflector with a shielding angle of little more than 20 deg. consequently qualifies for factory use only, for which it is, of course, eminently suitable.

(4.2) Average versus maximum luminance

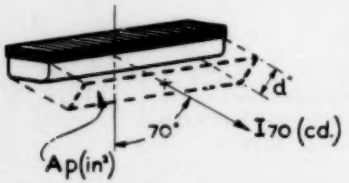
For a variety of reasons, it is preferable to base recommendations on average rather than maximum luminance. Not the least important of these is the comparative ease with which average luminance can be estimated. All that is needed is the relevant candlepower figure and a sample or drawing of the unit from which an estimate of the projected area of the diffusing media can be made.

It is desirable to base measurements on the projected area of the diffusing media only. This means that in the case of luminaires with translucent sides and opaque louvres below, the area of the latter will not be taken into account. Such surfaces are generally low in luminance (of the order of $\frac{1}{2}$ cd/in^2) and their projected area when viewed from the critical direction is so large that their inclusion might give a very low figure for the average luminance even though the translucent sides were virtually clear glass.

(4.3) Precautions against uneven luminance

It should be noted that the average value of luminance calculated in this way will not mean very much if the so-called " diffusing medium " is a glass or plastic so lightly etched that most of it is dark and only that part of it directly in front of the lamp is bright (see Fig. 12). Unfortunately, this is far from being an academic consideration; very poor diffusing materials are all too often used and precautions must therefore be taken against them.

One method would be to lay down some maximum allowable ratio between maximum and average luminance, but since the measurements must be made from a distance if they are to mean anything, this involves the use of photometric



$$\text{The Significant Luminance} = \frac{\text{Candlepower at } 70^\circ\ (I_{70})}{\text{Projected area (Ap)}}$$

Class	I_{70}/Ap cd/in^2
H	8 down to 6
G	6 " " 4
F	4 " " 3
E	3 " " 2
D	2 " " $1\frac{1}{2}$
C	$1\frac{1}{2}$ " " 1
B	1 " " $\frac{1}{2}$
A	$\frac{1}{2}$ or less

Fig.11. Determining the luminance classification of a luminaire. Measurements should be made with new (100-hour) lamps in clean luminaires.

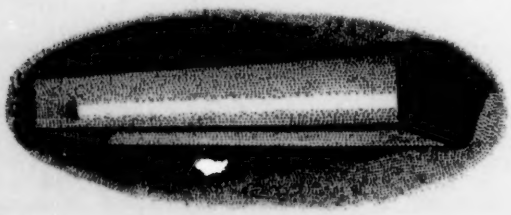


Fig.12. Luminaire with inadequately diffusing side panels. This should be treated as a bare lamp luminaire.

equipment which the majority of people have not got. It is therefore necessary to employ a qualitative test based on the appearance of the diffusing material when the unit is viewed from the critical direction. Experience has shown that a criterion of this kind can provide a much more definite method of distinguishing a good diffuser from a bad one than might at first be supposed.

(5) Conclusion

There is unquestionable need for simple practical guidance on permissible luminance limits, and this need is far more acute nowadays than it was before the tubular fluorescent lamp was introduced. The luminance of this type of light source is neither high enough to make it obviously glaring nor yet low enough to make it glare-free in all circumstances. Lack of simple rules indicating where the cheap, but treacherous, bare lamp unit can and cannot be safely used in working interiors is one of the principal reasons why fluorescent lighting design has been floundering along for some twenty years on a hit and miss basis—with, unfortunately, a high enough proportion of misses to have earned the fluorescent lamp itself a quite undeservedly bad reputation in many quarters.

One of the important advantages of the new tables, therefore, is that they give the lighting designer some indication of how and where the bare fluorescent lamp unit can be legitimately used, besides providing some useful guidance on how to minimise glare when laying out an installation.

It should be noted that the new method of setting luminance limits described in this paper does not pretend to be a set of watertight rules covering every conceivable situation. The method is simply intended as a guide to good practice in the majority of cases where diffusing luminaires or bare fluorescent lamps are used for general lighting purposes in working interiors. Moreover, it would be foolish to pretend that the tables in their present form are anything like a final answer to the problem of designing for glare control or that they are even necessarily accurate to the ± 20 per cent or so which the spacing of the luminance steps implies.

All that can be claimed is that since the tables make allowance for the observably important factors of room size and luminaire orientation and are reasonably soundly based on the available laboratory data, they are a substantial improvement on the old elementary table of luminance limits based on mounting height alone.

However, in the author's opinion, the method does have one noteworthy advantage in that, in spite of the subtlety which enables it to take into account all the above-mentioned factors, it is still simple enough for the practical man to use in his everyday work, thus opening the way for large-scale practical application of theoretical knowledge and speculation about glare, putting it to much more extensive test than is possible under laboratory conditions.

It in no way belittles the impressive amount of investigatory work that has already been done in this field to say that laboratory work alone cannot be expected to provide complete and detailed knowledge of glare for a long time to come. Intelligent practical applications of existing data is therefore likely to be of real help in showing up its strengths and weaknesses and in suggesting new lines of fundamental investigation, thus helping to accelerate the coming of a satisfactory "breakthrough" in this important field.

(6) References

(1) See Report 3.1.1.2 in the C.I.E. Compte Rendu, **1** (1955).

(2) Harrison, W., and Meaker, P., Illum. Engineering, **42**, 153-179 (1947).

(3) "Australian Standard Code for the Artificial Lighting of Buildings," A.S. No. CA. 30-1957. Published by the Standards Association of Australia, Science House, Sydney.

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(6) See, for instance, Stiles, W.S., Trans. Illum. Eng. Soc. (London), **17**, 241-264 (1952).

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Appendix 1

Worked Example

The following example indicates some of the ways in which the tables can help the designer to find a more satisfactory alternative when a proposed arrangement fails to measure up to the standard laid down in the S.A.A. code.

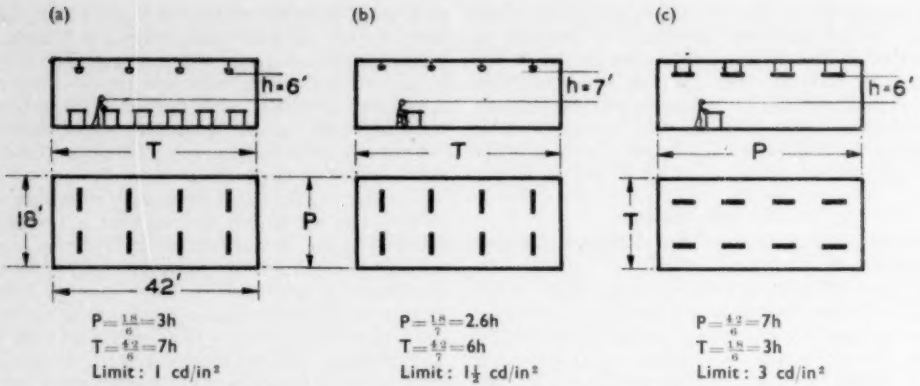


Fig.13. Influence of luminaire orientation and mounting height on the recommended luminance limit in a typical installation.

Let us assume that an office 18 ft. × 42 ft. is to be lit with fluorescent enclosed diffusing luminaires having a significant luminance approaching 1½ cd/in². The proposed layout is shown in Fig. 13a, and mounting height above eye level is 6 ft.

Here P=18 ft. and T=42 ft.

Since h=6 ft.

P=3 h and T=7 h.

The relevant luminance limit is found at the intersection of the P=3h column and the T=7h row in the main table. The value is 1 cd/in².

Since the proposed 1½ cd/in² units are above this limit the above-mentioned arrangements do not comply with the requirements of the code. However, there are ways of getting round this difficulty.

For instance, if the mounting height can be raised to 7 ft., P and T will become 2.6h and 6h respectively. Under these circumstances the table permits the use of 1½ cd/in² units. (Fig. 13b.)

A very much better way, however, would be to reorient the luminaires as shown in Fig. 13c, thus reducing the number of luminaires that can be seen broadside on at any one time. In these circumstances P and T become 7h and 3h respectively and the table permits the use of luminaires with a luminance of up to 3 cd/in². The proposed 1½ cd/in² will thus be well within the limit and give excellent glare control.

Moreover, if we can be sure that all occupants of the room will always work facing along it (a condition that frequently arises in offices lit by windows along one side) and will thus never see any units broadside on when they raise their eyes from their work, the auxiliary table can be used. Here, for P=7h and T=3h the limit is given as 6 cd/in². In other words bare fluorescent lamps could be used without exceeding the limits laid down in the code.

Appendix 2

Influence of Illumination Level on Discomfort Glare

The effect of changes in illumination level upon the glare factor G calculated by the formula :

$$G \propto \frac{B_s^m \cdot \omega^n}{B_b^p}$$

depends largely upon the relative weight given to ω and B_b, i.e. on the relative size of exponents n and p.

It will be seen that if the other factors remain constant an increase in the value of ω (by increasing the number of luminaires) will produce an approximately proportional increase in the value of B_b. The question as to whether the value of glare factor G will rise or fall (or remain the same) when the illumination level is raised by introducing more and more sources of the same luminance B_s will therefore depend on whether the exponent on B_b is greater than, less than, or equal to the exponent on ω.

There is evidence to suggest that the glare does increase somewhat when the illumination level rises, and though the measurements of Luckiesh and Guth[8] showed that Ward Harrison's assumed value of 0.6 for the ratio $^p/_n$ is probably too

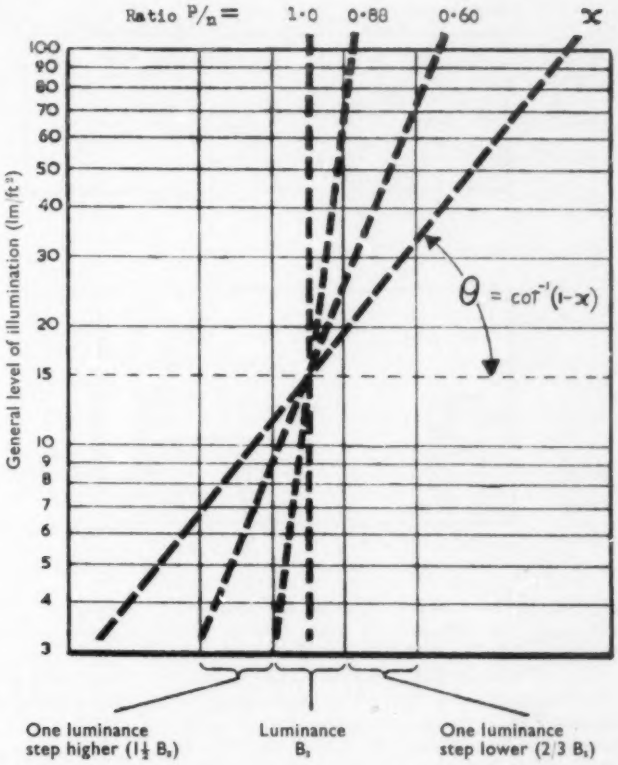


Fig.14. Chart showing how the choice of different values for the exponent ratio p/n varies the range of illumination levels covered by a single luminance limit taken from a range in which each limit is 50 per cent greater than the one below it.

small, the value suggested (namely 0.88) is still less than 1.

However, when employing a set of fixed luminance limits each about 50 per cent greater than the preceding one, we must also examine the range of illumination values covered by any one of these fairly wide steps on the luminance limit scale, for as exponent p on B_b approaches the value of exponent n on ω (i.e. 1.0) the above-mentioned range of illumination values becomes wider and wider.

This point is illustrated in Fig. 14, where it is shown that if one particular value of B_s gives exactly the chosen glare factor at an illumination level of 15 lm/ft², the assumption that $p/n = 0.6$ will necessitate the use of a luminance limit one step lower than B_s when the illumination level exceeds about 25 lm/ft² and the use of a limit one step higher than B_s when the illumination level falls below about 10 lm/ft².

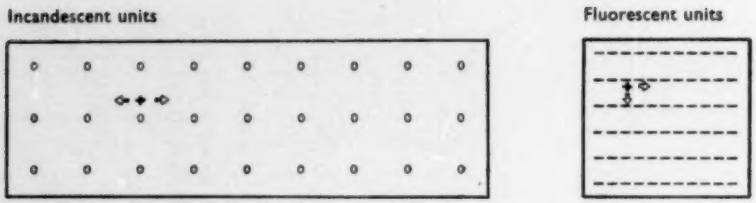
However, if we assume $p/n = 0.88$, the above-mentioned 10-25 lm/ft² range enlarges to about 3-70 lm/ft². Since uniformly distributed general lighting in excess of 70 lm/ft² is seldom found necessary in this country, a correction factor for illumination level therefore seems an unjustifiable complication.

Appendix 3

Practical Ways of Observing the Effects of Glare

The connection between luminaire mounting height and the degree of glare produced has long been recognised, but lighting engineers are sometimes reluctant to accept the idea that room size and luminaire orientation are no less important. Experience has shown that doubts about this point can be easily removed by performance of a simple subjective test along the following lines.

Find a long, narrow room lit by fairly bright general diffusing incandescent luminaires or bare fluorescent lamps set at right angles to the length of the room; and stand at a point about one-quarter of the way along it as shown in Fig. 15a.



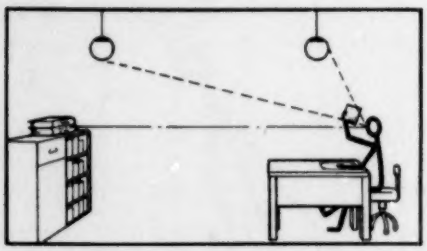


Fig.15 (above). To observe the influence of room size and luminaire orientation on direct glare, stand at position marked + in each case and compare the two views indicated by the arrows.

Fig.16 (left). If momentarily shading the eyes from the luminaires produces an immediately perceptible improvement in either comfort or visibility, this indicates the presence of a degree of glare likely to be troublesome in any interior where visual tasks are critical and prolonged.

By looking horizontally, first up, and then down, the room, the difference in glare can be readily detected.

An even more striking result is obtained when the observer stands near one corner of a large room lit by parallel rows of fluorescent luminaires or, better still, bare fluorescent lamps (see Fig. 15b). The marked difference in glare when viewing the installation parallel to the rows and at right angles to them can then be readily detected. Suitable installations can usually be found in large retail stores, and provided that the interiors are large enough and the luminaires bright enough to produce appreciable glare in the worst case, the experiment is a very convincing one.

When the glare is less pronounced the following simple test will help to reveal it. (This test is also of help in deciding whether an office installation is unduly bright.) From the working position, sight some object level with the eyes on the far side of the room and then momentarily shade the eyes from the luminaires (see Fig. 16). Any perceptible improvement in the visibility of the object produced by this manoeuvre is a fairly reliable indication of the presence of a degree of glare likely to be troublesome to people exposed to it continuously. This empirical test depends for its success on the fact that if discomfort glare in an artificial lighting installation is properly controlled, disability glare will be hardly perceptible. Conversely, if there is observable disability glare (even though it is so slight as to be quite unimportant in itself) it usually indicates that there is enough discomfort glare to build up serious discomfort over a period.

The above-mentioned tests are of great help in convincing oneself that the allowances made in the tables are in the right direction. Moreover a series of qualitative tests of this kind can be rapidly performed by anyone, once suitable installations have been found. Observations of this kind can also provide a quantitative check on the provisions of the table. However, in this case experienced observers must be used.

Since discomfort glare is cumulative in its effect (see Section 2.2) inexperienced people making a brief observation are apt to underrate the degree of glare present and to pronounce as "comfortable" installations which are likely to prove distinctly uncomfortable when one is exposed to the same conditions all day long. It was for this reason that experienced lighting engineers were used as observers in the field test referred to in Section 3.3 for whilst these individuals were not given any pre-instruction as to what they ought or ought not to consider "comfortable," their many years of experience enabled them to allow, consciously or unconsciously, for the cumulative effect.

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